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INVESTIGATION OF THE POLAR AURORAE, GEOMAGNETIC DISTURBANCES, AND THE IONOSPHERE AT HIGH LATITUDES

S. I. Isayev, Editor-in-Chief

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THE DIURNAL MARCH OF IONOSPHERIC WIND VELOCITY IN THE ZONE OF POLAR AURORAE AND S_D-VARIATION *3

M.I.Pudovkin

The diurnal march of the ionospheric wind in the auroral zones and the mechanism of excitation of the S_D-variation, as possibly caused by electric currents due to the dynamo action of the wind, are investigated by measuring the displacement of electric currents responsible for the magnetic bays. The S_D-variation is found to depend on the curve of the normal wind velocity component ($V_\perp$) and on the diurnal course of auroral intensity and can be defined (in relative units) by multiplying these two parameters.

One of the principal components of the field of a geomagnetic storm in the high latitudes is the disturbed diurnal variation of S_D. Although the geographical and time distribution of the electric currents responsible for this variation are known in great detail (Bibl.1, 2), the mechanism of excitation of the current system of the S_D-variation is still unknown. Evidently, one of the best founded theories of the excitation of electric currents in the ionosphere is the dynamo theory, which attributes the formation of such currents to the dynamo action of the ionospheric winds (Bibl.2). To verify the validity of this theory, it is necessary to investigate the system of ionospheric winds, primarily in the auroral zones, where the amplitude of the S_D-variation is maximum.

The most widely used method of investigating the ionospheric drifts is that of measuring the velocity of translation of nonhomogeneities of ionization by the aid of ground radio stations. However, such observations are exceedingly difficult and sometimes even impossible during geomagnetic disturbances, owing to the anomalous absorption of radio waves in the lower ionosphere. Moreover, only a small number of stations have measured the ionospheric drifts in the auroral zone. In the present work, therefore, we determined the ionospheric wind velocity from the displacement of the electric currents causing the magnetic bays (Bibl.3). This method undoubtedly has a number of serious disadvantages. First of all, the position of the currents responsible for some specific magnetic disturbance cannot be determined with sufficient accuracy from the data of a single station, without additional assumptions as to the shape of such currents and the intensity of the currents induced in the earth. The conventional assumptions that the currents are linear and that $\delta H_e = 2/3\ \delta H$; $\delta Z_e = 3/2\ \delta Z$, where δH_e, δZ_e are the components of the ionospheric current field and δH, δZ are the components of the observed perturbation field (Bibl.3, 4) /4
do not reflect the actual distribution of the ionospheric currents nor of those induced in the earth, and may thus lead to substantial errors in determining the absolute value of the rate of drift. It may, however, be assumed that these

* Numbers in the margin indicate pagination in the original foreign text.

errors are about equal at the various stations and that they are time-invariant; consequently, the drifts obtained from the magnetic data give a not too badly distorted idea as to the space-time distribution of the ionospheric wind velocity.

Secondly, from the magnetic data it is only possible to determine the component perpendicular to the current belt. However, since - as will be shown below - the currents are differently oriented at different stations, different components of the wind velocity will be measured there; to some extent, this makes it possible to judge the behavior of the entire vector.

At the same time, a determination of the ionospheric wind velocity from the magnetic data has the advantage that it can be performed at any magnetic observatory; thus, the rate of drift of ionization at the altitude of the current layer is automatically determined. The latter fact is particularly important, since the velocity of the wind in the ionosphere varies rapidly with altitude (Bibl.5, 6), which causes further difficulties in constructing the system of vectors in the dynamo region. Further than that, the electric currents in the ionosphere flow in the form of a belt of several hundred kilometers width so that, at each measurement of the velocity of their displacement, it is possible to determine the mean velocity of the drift over a considerable area and for a fairly long time (20 - 30 min), which imparts to these measurements a relatively great statistical weight.

In our investigation on the diurnal variation of the ionospheric wind velocity, we used the data of three geophysical observatories: Murmansk ($68^\circ 37'$ N; $33^\circ 3'$ E), Tiksi Bay ($71^\circ 35'$ N; $129^\circ 0'$ E), and College ($64^\circ 8'$ N; $147^\circ 8'$ W), which are located near the auroral zone, spaced a considerable distance apart, and covering about 180° in longitude. To check the convergence of the results we also used the data of Kiruna Observatory ($67^\circ 8'$ N; $20^\circ 4'$ E) which is only a short distance from Murmansk.

The diurnal variation of the normal component of the wind velocity ($V_\perp$) obtained for these stations for the winter months of 1957 - 1959 is shown in Fig.1, on which the local time is plotted on the abscissa and $V_\perp$ on the ordinate, with the plus sign corresponding to a drift from South to North, and the minus sign from North to South. As will be seen from the graphs, the curves of $V_\perp$ at all stations in question agree in their main features: In the evening hours, the wind blows from North to South and in the night and morning hours from /5
South to North, reaching a maximum around midnight or in the early morning hours. The existence of secondary maxima in the diurnal march of wind velocity at Murmansk and Kiruna can most probably be explained by the small number of observations made at these stations (25 - 30 bays), at considerable scattering of the individual measurements. In the case of a larger number of measurements, the resultant curves are much smoother (for example, at College, the march of $V_\perp$ is plotted from the data of 60 bays). But even at such a substantial scattering of the points as at Murmansk and Kiruna, the coincidence of the curves of $V_\perp$ at these stations is obvious, which speaks for the reliability of the results.

The slope of the curves of $V_\perp$, especially at the stations of Tiksi Bay and College, in spite of the absence of daytime observations, shows that there is an evident predominance of a 24-hour component in the diurnal march of the ionospheric wind velocity in the auroral region, instead of the 12-hour components observed in the middle latitudes (Bibl.5).

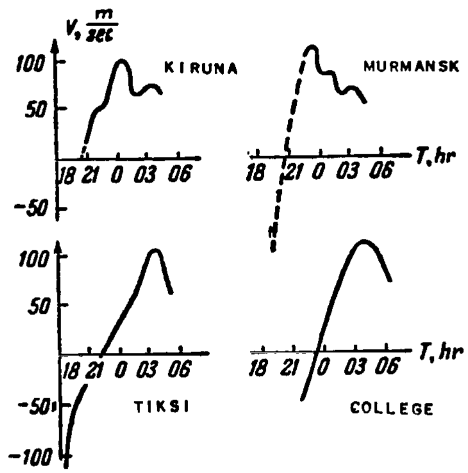

Fig.1

It is of interest that the curves of $V_\perp$ at different stations are mutually somewhat shifted. Thus, at Kiruna and Murmansk the curve of $V_\perp$ passes through zero at 2000 to 2100 h local time, while at Tiksi this takes place at about 2200 h and at College at about 2300 h. If, as is usually assumed by the dynamo theory (Bibl.2), the wind in the ionosphere exists independently of the invasion of corpuscular streams, and its variation is governed by the local time, then the result would appear rather strange at first glance. As already stated, the electric currents in the ionosphere are oriented differently at different stations, and different wind velocity components are measured at each station. Therefore, let us first consider how the currents are in fact oriented in the ionosphere. Figure 2 is a vector diagram (in the horizontal plane) of the

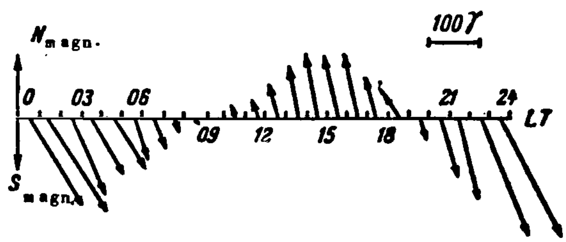

Fig.2

S_D-variation of the winter of 1958/59 at Murmansk. It will be clear from the graph that, for most days, the vector of δT_H does not change its direction, so that the mean direction of current, characteristic for a given station, can be selected with considerable confidence. This direction depends on the level of magnetic activity; with an increase in this activity, the vector of δT_H starts rotating counterclockwise. For this reason, the mean direction of δT_H for all the bays considered at the given station was taken as the direction of $V_\perp$. /6

In Fig.3, the local time T_a of passage of the curve of $V_\perp$ through zero is plotted as a function of the value of the angle φ made by the vector of δT_H with the geographic meridian (or by the current belt with the geographic parallel of latitude); the positive values of the angle φ are here measured clockwise. As

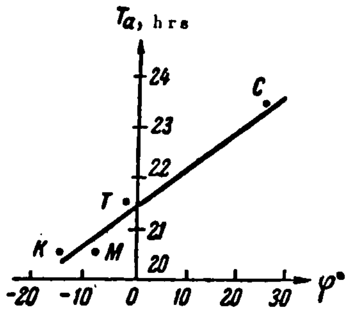

Fig.3

indicated by the graph, T_a increases almost linearly with the angle φ. This dependence of T_a on φ evidently can be most naturally explained by the fact that the wind velocity vector does not maintain its direction throughout the day, but rotates clockwise, becoming parallel to the mean direction of the currents at the given station ($V_\perp = 0$) at various times, depending on the angle φ. Figure 3 shows that the vector $\bar{V}$ rotates clockwise, as it should do in the Northern Hemisphere (Bibl.5). The velocity of rotation is about 12°/hr, which is entirely consistent with the fact that the 24-hour component predominates in the diurnal march of the curve of $V_\perp$ and that the wind is directed toward the geographical West at about 2130 h local time and to the North, at 0300 h (at the same time, at Tiksi Bay, when $\varphi \approx 0$, the value of $V_\perp$ reaches its maximum). The absolute wind velocity apparently varies only slightly during the night, since the maximum values of $V_\perp$ observed at different stations at different times is about the same (about 100 - 110 m/sec).

Let us consider how the diurnal march of the ionospheric wind velocity, obtained in this manner, is related to the observed S_D-variation of the geomagnetic field. A comparison of the curves of $V_\perp$ and δH at all the experimental stations (for example, for Murmansk, Figs.1 and 2) shows that the shape of the S_D-variation is determined in its main features by the slope of the $V_\perp$ curve. In fact, the diurnal march of δH is a simple wave, and the points $\delta H = 0$; $|\delta H| = \max$ approximately coincide with the points $V_\perp = 0$ and $V_\perp = \max$. Here, the direction of the wind is found to be as predicted by the dynamo theory, i.e., at $\delta H > 0$, the wind is directed from North to South, while at $\delta H < 0$, it is directed from South to North. /7

It has been shown (Bibl.7) that the shape of the S_D-variation is determined not only by the diurnal march of the ionospheric wind velocity, but also by the diurnal march of auroral intensity; it can be obtained (in relative units) by

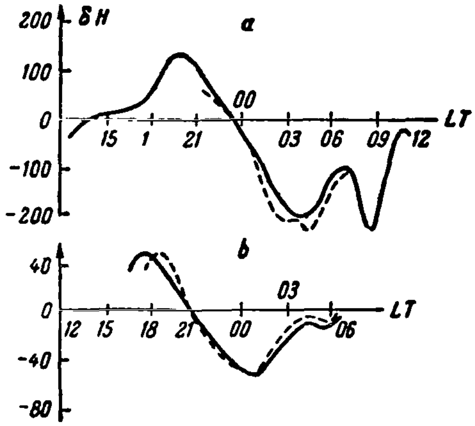

Fig.4

multiplying these two variants. To demonstrate this proposition, we show in Fig.4b, according to the data of (Bibl.7), the observed and calculated variations of δH at Lovozero ($\varphi = 67^\circ 59'$, $\lambda = 35^\circ 05'$). The agreement of the theoretical and observed curves is obvious.

The combination of the diurnal march of the auroral intensity and of the ionospheric wind velocity at College is peculiar: The point $V_\perp = 0$ occurs at a time close to midnight while, at this time, there is a maximum of auroral displays (Bibl.8). This indicates that the wind in the ionosphere is evidently not connected with an invasion of corpuscular streams and is determined instead by processes inherent in both the perturbed and the quiet ionosphere. In spite of the fact that aurorae are particularly frequent at midnight, δH is zero at that time, in accordance with the diurnal march of $V_\perp$ at College, confirming the substantial part played by the ionospheric wind in the formation of the S_D-variation. Figure 4a gives the calculated and observed variations of δH at College. The march of the emission intensity at $\lambda = 3914$ Å, according to data by Davis (Bibl.8), is taken as the diurnal march of auroral intensity. The graph clearly indicates that at College, just as at Lovozero, the calculated and observed curves are in rather good agreement.

The above data speak for the view that, in all probability, the electric /8
currents responsible for the field of S_D-variation can be explained by the dynamo action of the ionospheric winds, which exist independently of the invasion of corpuscular streams and vary with the local time.

In this connection, it is of interest that, as noted by a number of investigators, also the march of the S_D-variations occurs in accordance with geomagnetic time. For example, Davis (Bibl.9) showed that the change in sign of δH is usually accompanied by a change in the direction of motion of the inhomogeneities of auroral intensity. This "reversal" of motion of the aurora occurs

Station	D_{gm}	D	φ	T_{astr}	T_{gm}
Kiruna	-25	+12	-6	20.5	22.0
Murmansk	-22	+12	-8	20.5	22.0
Dikson	-10	+29	-10	19.5	20.0
Tiksi	+ 8	+14	0	21.5	21.0
College	+25	+29	+24	23.0	21.0

at the different stations at different local times, but at approximately the same geomagnetic time. Let us attempt to explain this fact from the data obtained on the diurnal variation of the ionospheric wind velocity. For this,

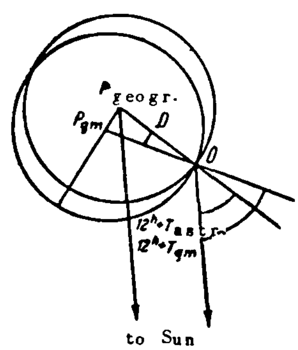

Fig.5

let us consider in more detail the direction of the current belt at various stations, given in the Table. As already stated, the direction of the S_D-currents varies little during the day, but depends markedly on the level of magnetic activity. The values of the angle φ obtained from an analysis of the magnetic bays may therefore fail to coincide with the values of the angle φ for the S_D-currents; the value of φ given in the Table is determined directly from the vector diagrams of the S_D-variation for the stations involved. The same Table gives the value of the geomagnetic (D_{gm}) and magnetic (D) declination at these stations. It should be noted that the value of D_{gm} was taken from the map, and is therefore given with accuracy to within 5°. The Table shows that the direction of the currents is intermediate between the directions of the geomagnetic /9
and magnetic parallels. But even with so great a difference between the magnetic and geomagnetic parallels as at Murmansk, Kiruna and Dikson, where (D_{gm} - - D) is of the order of 40°, the value of φ differs from D_{gm} by no more than 20°, and for most stations one can apparently assume $\varphi \approx D_{gm}$. As shown above, a change in sign of δH at stations in the auroral region is concomitant with a change in sign of $V_\perp$ which, according to Fig.3, occurs at the instant T_a =

$= 2150 \text{ h} + \dfrac{\varphi^{\circ}}{12^{\circ}}$ of local time. Figure 5 indicates that the geomagnetic time differs from the local time at a given point by the value of the angle $\Delta T = -D_{gm}$. Consequently, according to geomagnetic time, the change in sign should take place at the instant $T_{gm} = T_{a} - \dfrac{D_{gm}}{15^{\circ}} \approx 2150$ h, i.e., at the very same instant at the different stations. It will be clear from the Table that $\delta H = 0$ is actually observed at approximately this time.

Thus, the march of the S_D-variation according to geomagnetic time is not inconsistent with the dynamo theory and is explained by the fact that the velocity vector of the ionospheric wind becomes parallel ($\delta H = 0$) or perpendicular ($|\delta H| = \max$) to the zone of invasion by corpuscular streams at different stations at different times, depending on the value of the angle φ which latter, in turn, is determined by the geomagnetic coordinates of the points of observation.

However, it must be noted that, at the time when $V_{\perp} = 0$ occurs at a given station, the electric current over the station continues to exist (the current closing the central current stream and forming the middle-latitude or polar eddy of the S_D-variation); consequently, δH at this time may also differ from zero, especially at stations located outside the auroral region itself. For this reason, the dependence of the time of passage of δH through zero on the value of the angle φ, and the march of the S_D-variation according to geomagnetic time, most probably can be considered merely as tendencies.

CONCLUSIONS

1. A diurnal wave predominates in the diurnal march of the ionospheric wind in the auroral region. The direction of the wind at the point of observation is determined by the local time, and is from East to West at 2130 h and from South to North at 0300 h.

2. The march of the S_D-variation is determined by the slope of the diurnal variation of the ionospheric wind velocity and the auroral intensity.

3. The currents responsible for the field of the S_D-variation owe their origin to the dynamo action of the ionospheric winds.

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MORPHOLOGY OF HYDROGEN EMISSION IN POLAR AURORAE */11

L.S.Yevlashin

The emission of hydrogen H_α of an intensity of not less than 150 Rayleighs in polar aurorae is correlated to the presence of a sporadic E_s layer, showing more intense emission at a relatively low critical frequency (f_0E_s = 4 - 5 Mc) of this layer. No correlation was found between hydrogen emission and ionosphere parameters in the F layer. Apparently, deexcitation of protons connected with the aurorae takes place primarily at low altitudes (110 - 130 km).

Hydrogen emission H_α with an intensity of not less than 150 Rayleighs in the aurorae, according to observations at Murmansk ($\Phi = 64^\circ$) during the period from 1957 to 1961 was registered by a C-180-S camera in almost half of the nights on which observations were made. Not once did we succeed in detecting the hydrogen lines without at least some sign of aurorae, i.e., in the absence of the most characteristic auroral bands $1NGN_2^+$ from the spectrum. On the other hand, on the occasional days when no hydrogen emission was observed at Murmansk while there was an aurora, the hydrogen lines were noted on Tromsö with a photoelectric spectrometer (Bibl.1). All these data evidently permit the assumption that the proton streams, responsible for excitation of the aurora, are present everywhere when the diffuse forms of the aurora exist.

Considering the distribution of the hydrogen emission over the night sky, we note that the proton fluxes and the radial forms of the aurora are spaced at a certain distance in space. The H_α emission is noted directly only in the diffuse forms: uniform arcs (HA), bands (HB) and diffuse glow (DS) correlating with the intensity of the green line [OI]λ5577 Å. At times, the hydrogen emission is not concentrated, such as in very bright radial aurora forms (intensity III - IV) and in red aurorae of type B, in whose spectra, in addition to an increase in intensity of all principal emissions (λ6300 Å, λ5577 Å and $1NGN_2^+$), the $1PGN_2$ bands are sharply intensified. In the red aurorae of type A (RR, RP, DS) characterized by a considerable increase in intensity of the red oxygen line λ6300 - 6364 Å, no direct detection of hydrogen was possible, throughout the time of observation.

In view of the fact that hydrogen emission is related to the diffuse forms of aurorae, it is very difficult to determine its boundaries on the celestial vault. For example, it is often observed over the entire sky (Bibl.2); for this reason, the term "hydrogen emission" in the present work is to mean the /14
region of its maximum concentration.

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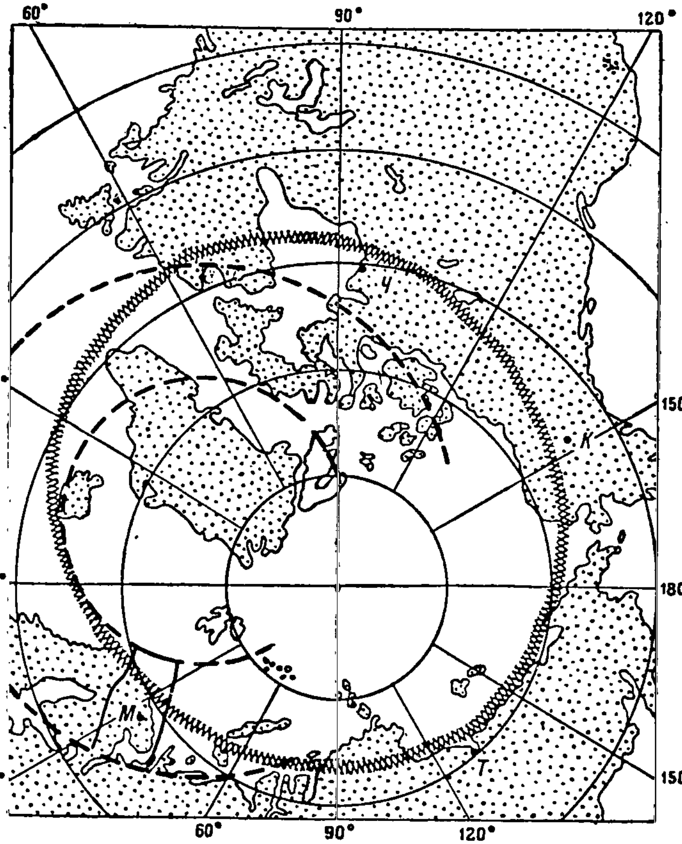
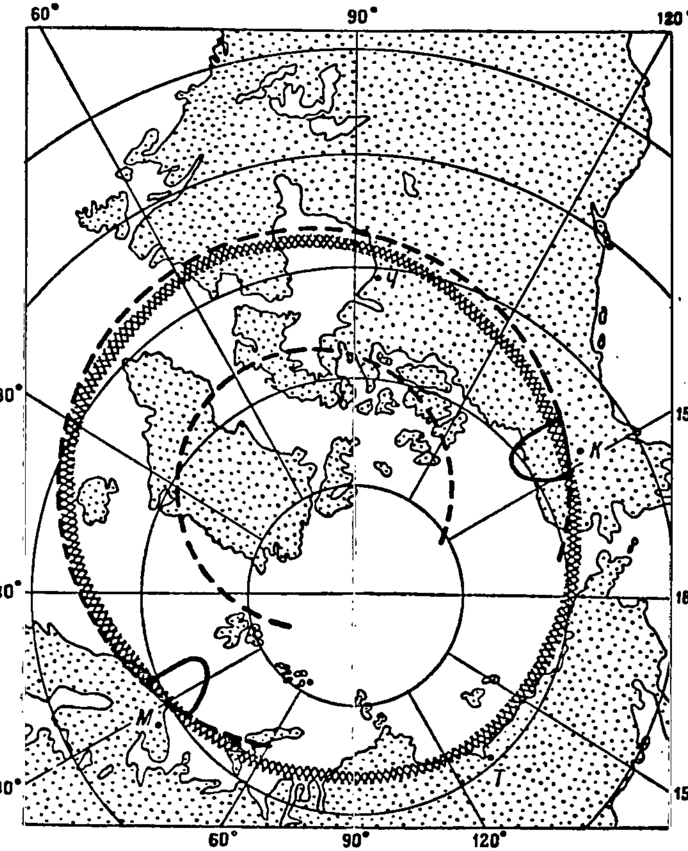


Feb.10-11, 1958 $2^h00^m UT$

Fig.1



Feb.10 11, 1958 $3^h30^m UT$.

Fig.2

During the International Geophysical Year it was noted that hydrogen emission, as a rule, undergoes a latitudinal drift during the day (Bibl.2, 3, 4, 5). Thus, according to observations at Murmansk, this emission is observed in the evening, on the average one hour after sunset, at 9° above the horizon in the southern half of the sky; toward midnight, it is concentrated in the

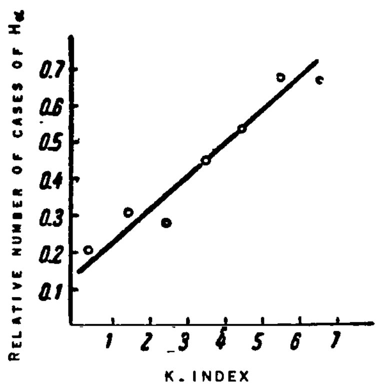


Fig.3

southernmost portion and by morning again shifts toward North. This phenomenon was also observed in subsequent years (Bibl.6). However, on some days, characterized by strong magnetic disturbance, the patterns of latitudinal drift were markedly disturbed, and the hydrogen emission was observed to the south of Murmansk in the evening and morning twilight. On the other hand, on magnetically quiescent days, the hydrogen emission appears in the north only around midnight, and disappears there also after a certain time. Its intensity increases as it moves toward the lower latitudes, reaching a maximum at latitudes of the order of 58 - 60°.

It was found earlier (Bibl.5, 7) that the zone of hydrogen emission along the meridian may be very wide (of the order of 2000 km). On the basis of literature data (Bibl.8, 9), it has recently been found that the region of hydrogen emission stretches along the latitudes close to the aurora region for a considerable distance, covering the dark side of the earth (Bibl.6). This annular belt, which to some extent resembled the auroral belt (Bibl.10), shifts in space during the day over the polar region as a whole, descending at night to the lower latitudes and rising by morning to the higher ones. Figures 1 and 2 give a map of the polar region of the Northern Hemisphere, showing the position of this belt at various periods of time (Feb.10 - 11, 1958). The cross hatching shows the zone of maximum auroral frequency, according to Fritz. The two concentric semicircles show the idealized projection of the hypothetical region of the hydrogen emission on the earth's surface. The heavy line indicates the boundaries of the region of the recorded hydrogen emission, while the broken lines give the hypothetical boundaries.

In view of the absence of observational data on hydrogen emission in the polar regions, the annular belt on the day side, which runs precisely through this region, is not shown as a closed belt. It has been established (Bibl.11) that in the polar region high aurorae, spectroscopically belonging to /15 the red aurorae of type A in which no appreciable hydrogen radiation is noted (Bibl.5, 12), are predominant in the entire region. It may thus be postulated that the polar region is a forbidden zone for the penetration of the main mass of protons, and the belt of hydrogen emission on the day side is in fact interrupted.

Since the hydrogen emission is closely related to the aurora, which is commonly known to depend on the extent of geomagnetic activity, it is natural that the statistical probability of observing the hydrogen emission increases with geomagnetic activity. Figure 3 shows the relation between the relative number of cases of the appearance of H_α emission and the K-index. However, this comparison, which is based on mean values, does not reflect the true character of the influence of the proton flux on the earth's geomagnetic field. Thus, a

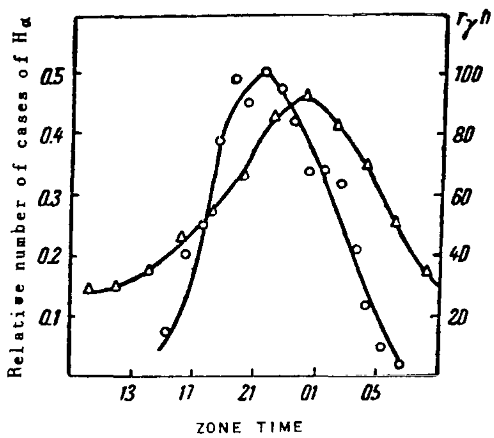


Fig.4

comparison of the curve of relative frequency of hydrogen emission during the course of the day with the march of the hourly amplitudes of the horizontal component of the earth's magnetic field (Fig.4) indicates that the maximum frequency of appearance of the hydrogen emission is 3 - 4 hrs ahead of the maximum of magnetic disturbance. Further than that, the hydrogen emission is present in the quiet diffuse forms and becomes invisible in the bright and radial forms, which is evidence that hydrogen is observed primarily in periods of relative magnetic quiescence. However, there exists a certain relationship between the current systems in the ionosphere responsible for the magnetic bays and the wide uniform arches comprising the hydrogen emission. Thus, in most cases (80%) such arches coincide with the direction toward the center of gravity of the current system (Bibl.13).

A comparison of the data on hydrogen emission with the ionospheric data /16
shows that the hydrogen emission is more compatible with the presence of a sporadic E_s layer (mostly of the type r - 65%) and far less with complete absorption B - 24%. No correlation at all exists between the intensity of the hydrogen radiation and the critical frequency of an E_s layer. The most intense hydrogen radiation (over a thousand Rayleighs) is always observed in the

presence of a sporadic layer with a relatively low critical frequency (f_0E_s = = 4 - 5 Mc). At the same time, the presence of a sporadic layer with a high critical frequency (of the order of 10 - 13 Mc) is correlated with very bright radial auroral forms, without hydrogen emission. No correlation whatever could be established between the hydrogen emission and the ionospheric parameters in the F region.

The close connection of hydrogen emission with the green oxygen line [OI]λ5577 Å in the diffuse auroral forms with a sporadic E_s layer, as well as the spatial correlation between hydrogen emission and electric currents in the ionosphere, permit the assumption that the de-excitation of protons connected with the aurora takes place primarily at a relatively low altitude (of the order of 110 - 130 km).

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SOME FEATURES OF THE LATITUDE DRIFT OF POLAR AURORAE *<u>/17</u>

L.N.Mal'ko

The latitude drift of polar aurorae is plotted against local time, on the basis of camera recordings at Russian and Alaskan Arctic stations. The pattern of auroral motion proceeds over geomagnetic latitudes and is influenced by magnetic field disturbances, shifting farther south at greater disturbances. The belt shifts southward in the evening, shows a variation in width during the night, and moves northward again at daybreak, at a total drift of 10 - 15° and a rate of displacement of up to 1000 m/sec.

It is clear from the material obtained at 13 stations of the Soviet part of the Arctic for the period 1957 - 1959, by the aid of C-180 cameras, that a strong glow of the auroral belt is superimposed on the almost uniform glow of the polar cap. The belt undergoes a latitudinal drift (of the order of 15°) during the night, moving toward the south in the evening and returning toward the north in the second half of the night. The velocity of the drift of the aurora is as high as 1000 m/sec. The width and intensity of the belt vary continuously.

Observations of the H_α emission at College (Alaska) in the winter of 1958-59 with a C-180-S spectrograph showed a systematic drift of H_α from North to South during the first half of the night, and an inverse drift during the second half of the night (Bibl.1). From the materials obtained with all-sky cameras at five Alaskan stations at geomagnetic latitude 60 - 70°, the conclusion has been drawn (Bibl.2) that a southward motion of the aurora from the "latitudinal position of the source" predominates at these latitudes. However, the total material for the five stations showed a difference in the motion of the aurora over each of these stations, which occupy somewhat different positions relative to the auroral zone.

To define the latitudinal motion of the aurora over stations in the zone, and North and South of it, the probability of motion of the aurora (Figs.1, 2, 3) to the South (heavy line) and to the North (line with crosses) was plotted against the local time. The probability of auroral forms remaining motionless for half an hour is shown by the dashed curve. The study was based on photographs taken with C-180 cameras. The motion of a given form was determined visually from the passage of the lower edge of the aurora across the intersection of lines of equal zenith distances with the north-south line. The Table gives a list of the stations, the geomagnetic coordinates, the period of

* Numbers in the margin indicate pagination in the original foreign text.

observation, and the number of nights with aurora displays, used in the work-up.

The aurorae above these stations may be divided into three types, according to the character of their motion: 1) those lying in the interval of geomagnetic latitude 60 - 69° (stations Muostakh, Tiksi Bay, Cape Shmidt, Cape /18

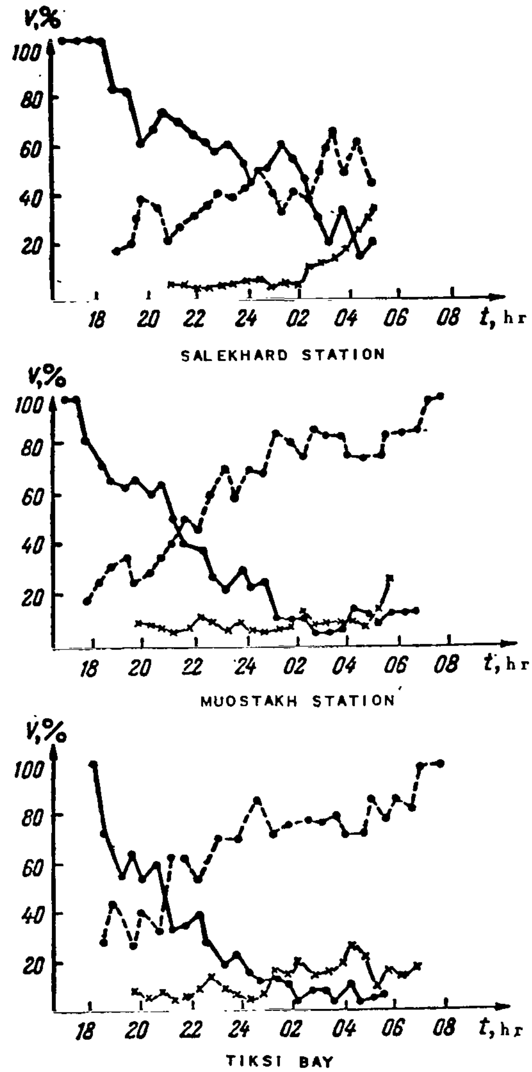


Fig.1

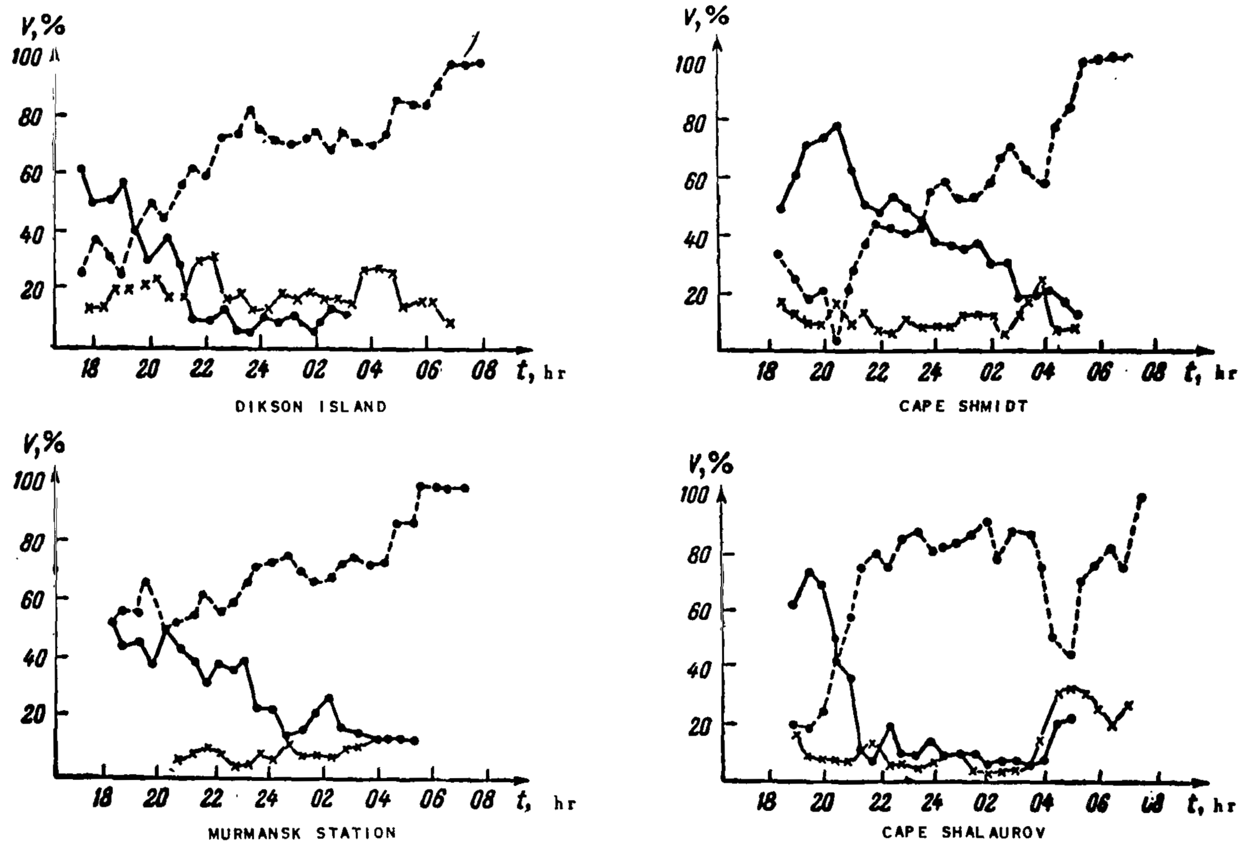
Shalaurov, Dikson Island, Murmansk, Cape Chelyuskin, SP-6; 2) lying South of latitude $\Phi = 60^{\circ}$ (station Salekhard and Aldan); 3) lying North of latitude $\Phi = 69^{\circ}$ (stations Vize, Piramid, and SP-7).

In the belt of $\Phi \approx 60 - 69^{\circ}$, with the onset of night, the aurora appears in the zenith above certain latitudes. At intense disturbance of the magnetic field, an "instantaneous zone" appears South of the mean statistical position of the main zone. On such nights the aurora appears in the zenith in the early evening, above the Murmansk station. At weak disturbance of the magnetic field, the "instantaneous zone" appears to the north of the mean statistical position of the main zone. After this, the aurora over the Murmansk station drifts down from North in the early evening. The same pattern is observed for stations somewhat South of the mean statistical position of the main zone. It is clear from Figs.1 and 2 that, for the stations at Muostakh, Tiksi Bay, Cape Shmidt, Cape Shalaurov, Dikson Island, and Murmansk, the following pattern of auroral motion is characteristic:

In the early evening hours, the aurora moves from North to South (heavy line). The probability of such motion increases with decreasing latitude. Thus, for the stations Muostakh, Tiksi Bay it begins at 100%, while for the /19

Station	Geomagnetic Coordinates		Period of Observation	Number of Nights
	Latitude	Longitude		
ALDAN	47.4°	191°	1958—1959	
SALEKHARD	57.3	149.7	1957—1958	
			1958—1959	42
MUOSTAKH	60.1	192	1958—1959	31
TIKSI BAY	60.6	191.3	1958—1959	54
CAPE SHMIDT	62.1	227.4	1957—1958	
			1958—1959	68
CAPE SHALAUROV	62.6	199.6	1958—1959	36
DIKSON ISLAND	63	161.4	1957—1958	
			1958—1959	64
MURMANSK STATION	64	126.5	1957—1958	
			1958—1959	96
CAPE CHELYUSKIN	66.2	176.5	1958—1959	38
SP-6	~69	~200	1957—1958	40
VIZE ISLAND	69.3	163.8	1958—1959	32
PIRAMID STATION	74.5	129.8	1957—1958	
			1958—1959	56
SP-7	~77	~199	1957—1958	

stations Cape Shmidt, Cape Shalaurov, Dikson Island, and Murmansk it is located within the limits of 60%, since here the aurora flaring at the zenith and covering the entire sky already makes an appreciable contribution. It is quite difficult to determine the direction of their motion, so that such phenomena are considered cases of "stationary" aurora. The probability of motion of the aurorae to the South gradually declines toward morning, while the probability of quiescent aurorae increases to 100%. This is explained by the increasing brightness of the background in the morning hours, the break-up of the bright moving forms, and the slow motion of the faint patches. The motion of the aurorae to the North of the zone (line with crosses) begins almost simultaneously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DIKSON ISLAND
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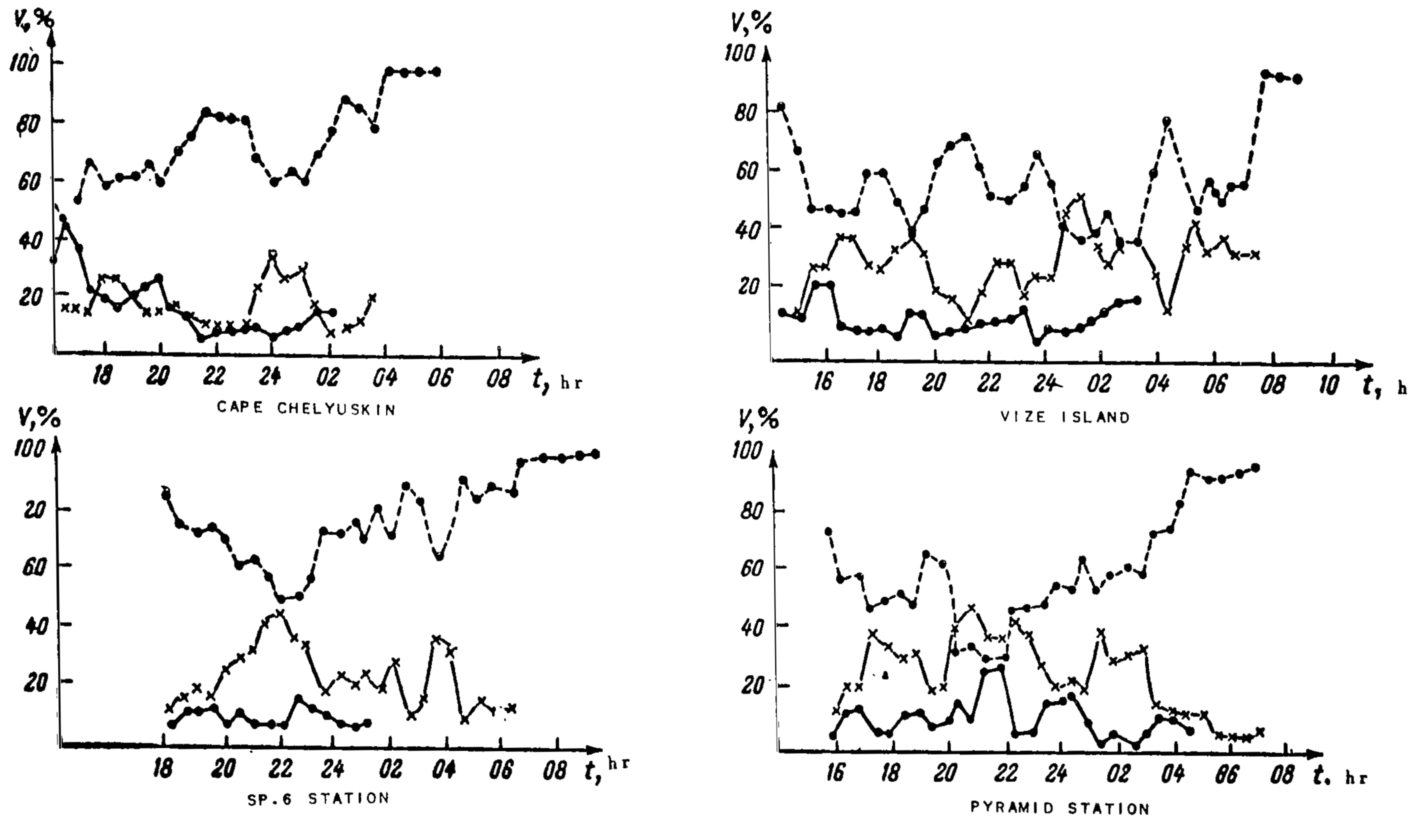
MURMANSK STATION
CAPE SHALAUROV

Fig.2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VIZE ISLAND
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18 20 22 24 02 04 06 08 t, hr
SP.6 STATION
V,%
100
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16 18 20 22 24 02 04 06 08 t, hr
PYRAMID STATION

Fig.3

with the motion toward South, i.e., the width of the auroral zone pulsates during the course of the night.

In the morning hours, the number of aurorae moving toward the zone increases. It should be noted that there are more aurorae going South than returning. This phenomenon, as previously noted (Bibl.2), is explained by the partial disappearance of the aurorae at low latitudes. The Cape Chelyuskin station lies in the zone, so that here a southward and northward motion is almost equiprobable. At Station SP-6, showing a drift far North of the zone, a high percentage of aurorae in the zone itself was observed, but in the morning hours they did not return to the zone, but continued to move away from the zone, i.e., the auroral belt shifts toward the Pole in the morning. /22

The shift of the auroral belt toward the Pole has latitudinal boundaries. Thus, in the region of drift of Station SP-7 ($\Phi \simeq 77^{\circ}$) no auroras coming from South were observed. At stations Vize and Piramid, on the polar cap, a large number of aurorae were observed that did not come from the zone but originated with almost equal probability in any part of the sky (more or less uniform glow of the polar cap). For these stations, aurorae still come from the zone. As for the aurorae observed at Station SP-7, they can be explained by the glow of the polar cap. The aurorae observed in the zone (glow of the belt) and outside the zone (glow of the polar cap) differ in several properties. Thus, the intensity of the aurorae in the polar cap is as a rule not over 1, the aurora displays are brief and, probably, appear at a higher altitude than in the zone (Bibl.3, 4).

At the Salekhard station, far to the south of the zone, the aurorae in the evening drift down from the zone (solid line in Fig.1), remain at the zenith (dashed line), and then either leave the zone (curve with crosses) or die out. In the morning hours, the motion of the aurorae toward the zone commences. At the Aldan station, throughout the 1958 - 1959 season, only a few cases of aurorae at the northern horizon were observed.

Thus, the pattern of auroral motion takes the following form: On the substantially homogeneous glow of the polar cap a strong auroral belt [called a ring elsewhere (Bibl.5)] is superimposed. This belt becomes observable in the zenith at the onset of darkness, over certain latitudes. The stronger the disturbance of the magnetic field, the lower the latitudes at which the aurora appears in the evening hours. The belt then widens to the north and to the south. The width of the belt varies during the course of the night, undergoing breaks that may possibly be due to a decrease in intensity. The forms do not persist over the entire belt, and their coincidence may be attributable to pure chance. With the onset of daylight, the belt moves northward but does not closely approach the Pole, i.e., it obviously has latitudinal boundaries. According to (Bibl.6), the total drift during the course of the night is of the order of 10 or 15°. According to our data, the aurorae drift in a belt of approximately the same width.

The NS and SN rate of displacement of the aurora reaches 1000 m/sec. Its mean velocity, based on 180 measurements, is of the order of 400 m/sec. No differences in velocity away from the zone or toward the zone were noted.

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THE ORIENTATION OF HOMOGENEOUS ARCS OF POLAR AURORAE AND THEIR CORRELATION WITH THE CURRENTS OF MAGNETIC DISTURBANCES *\/24

V.K.Roldugin and G.V.Starkov

The diurnal march of azimuths and the position of the auroral arcs, oriented along the spiral maximum probability of appearance of aurorae, are discussed in their relation to magnetic disturbances over the polar cap, using plottings based on photographs obtained with an all-sky camera. Most arcs are grouped about the "night" spiral, showing two maxima of appearance, of R_{max} 550 and 1100 km. At local geomagnetic midnight, the arcs make a large angle with the currents of magnetic disturbances, but are parallel before and after.

In this study we investigated the morphology of the linear forms of auroral displays, with special reference to homogeneous arcs, on all-sky (Aska) films from a C-180 camera. The zenith distances to an arc, obtained from the distortion curve, were converted into linear distances to the point of its projection on the earth's surface, allowing for the curvature of the earth. The zenith distances were measured every 15° in azimuth, and the height of the lower edge of the arc was taken as 110 km. The projections of the arc were plotted on a map in direct stereographic projection at the scale 1 : 10,000,000. We also determined the radius of curvature of the projection of the arc.

Before starting our discussion, we must evaluate the accuracy obtainable by rating all-sky exposures with a C-180 camera and projecting the aurora onto a map, since this procedure plays a very important part in the interpretation of the results.

We will consider that, for $r = 100 \cdot n$ km, we have $\Delta r = 10 \cdot n$ km where r is the distance from the station to the point of projection of the arc onto the map. In general, for r = 100 km, we have $\Delta r < 10$ km, but on the map 10 km corresponds to 1 mm, which is also the mean accuracy of plotting the data. It is known that a stereographic projection preserves all angles. The linear distortions are expressed by the formula:

$$m = \frac{2}{1 + \cos z},$$

where z is the angular distance to the pole (Bibl.1). For Murmansk, m = 1.034; for Tiksi Bay, m = 1.030; for Dikson Island, m = 1.021. The maximum error for 100 km is 3.4 km, i.e., in all cases the projection error is less than the random error of measurement.

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Let us now estimate the errors of determination of the radius of curvature of the projection of an arc. Let the coordinate system xy have its origin at the center of the circle to which the arc is tangent (Fig.1). In the system $x'y'$, we have $x' = x + A = x + r_0 \sin \varphi_0$, $y' = y + b = y + r_0 \cos \varphi_0$. The rectangular system $x'y'$ will be replaced by a polar system with its center at the point of observation. Then, $x = r \sin \varphi - r_0 \sin \varphi_0$, $y = r \cos \varphi - r_0 \cos \varphi_0$, where φ is measured clockwise from the y' axis. The equation of the circle in this system is written in the form /25

$$R = \left[r_0^2 + r^2 - 2rr_0 \cos (\varphi - \varphi_0)\right]^{1/2} = \psi (r, r_0). \tag{1}$$

From the theory of errors we have

$$\Delta R = \frac{\partial \psi}{\partial r} \Delta r + \frac{\partial \psi}{\partial r_0} \Delta r_0,$$

since R is independent of φ and φ_0. In connection with the fact that the error of determination of r_0 is completely determined by the error of Δr, we can write

$$\Delta R = 2 \frac{\partial \psi}{\partial r} \Delta r = 4\Delta r \frac{r - r_0 \cos (\varphi - \varphi_0)}{\sqrt{r_0^2 + r^2 - 2rr_0 \cos (\varphi - \varphi_0)}} .$$

Let us consider two cases for our estimate of the error of measurement. For $\varphi = \varphi_0$, we have $\cos (\varphi - \varphi_0) = 1$ and thus $\Delta R = 4\Delta r$. For $\Delta r = 40$ km, we have

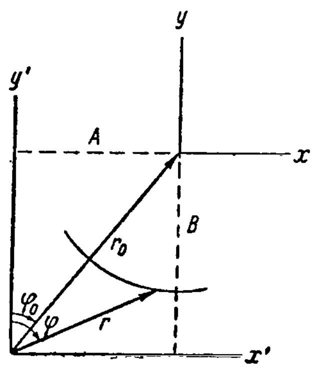

Fig.1

$\Delta R = 160$ km. The error of measurement in this case is maximum since, for $\varphi = \varphi_0$, the quantity r is as a rule less than 300 km. For $\cos (\varphi - \varphi_0) = 0$, we have $\Delta R = \frac{4\Delta r \cdot r}{\sqrt{r^2 + r_0^2}}$; usually $r < r_0$. Hence,

$$\Delta R = \frac{4\Delta r \cdot r}{\sqrt{r^2 + r_0^2}} < \frac{4\Delta r \cdot r}{\sqrt{2}} \approx 3\Delta r = 120 \text{ km}.$$

Thus, we can conclude that the error of measurement of ΔR does not exceed 160 km which, for R = 500 km, amounts to about 30%. This is the maximum relative error.

Let us now consider the error of measurement of the azimuth $\alpha = 90^\circ + \varphi$ and $\Delta\alpha = \Delta\varphi$. Solving eq.(1) for φ, we obtain:

$$\varphi = \varphi_0 + \arccos \frac{r_0^2 + r^2 - R^2}{2rr_0} = \vartheta(r, r_0),$$

$$\Delta\varphi = \frac{\partial\vartheta}{\partial r}\Delta r + \frac{\partial\vartheta}{\partial r_0}\Delta r_0 = 2\frac{\partial\vartheta}{\partial r}\Delta r = \frac{(r^2 - r_0^2 + R^2)\Delta r}{r\sqrt{2r^2R^2 + r_0^2 - (r_0^2 - R^2)^2 - (r_0^2 - r^2)^2}}.$$

Let R = 1000 km, r_0 = 1200 km, r = 300 km, Δr = 40 km be the values most frequently encountered. We then obtain $\Delta\varphi = 0.07 = 4^\circ$.

Investigators have recently begun to pay considerable attention to the azimuths of auroral arcs (Bibl.2 - 9). This question has been most fully considered by B.Hultgvist (Bibl.9), who analyzed an extensive amount of material obtained by various authors. However, his interpretation evokes certain objections. In the diurnal march of homogeneous auroral arcs, according to some data, a "break" of the azimuths is observed in the evening hours, and is interpreted from the viewpoint of Alfven's theory (Bibl.10), which predicted such a break at 0600 h local geomagnetic time. It is true that the break is in fact observed at a later time, 0700 - 0800 h, but B.Hultgvist then connects the orientation of the arcs to the shape of the zone obtained by projection onto the earth's surface of the equatorial ring along the magnetic lines of force (see Bibl.11). A rather good agreement of the mean orientation of the arcs with the zone is obtained, but this treatment excludes in principle any diurnal variation of the azimuth. On the other hand, the diurnal march of the azimuths and arcs in the polar cap is explained by the system of S_p-currents. /26

This explanation is based on an external similarity, but does not correspond to reality. Specific measurements of the orientation of auroral arcs in the presence of vortical S_p-variations have been reported (Bibl.12), which indicate that these currents do not exert an appreciable influence on the orientation of the aurorae (the S_p-currents and the aurorae in some cases are mutually perpendicular). In short, to explain different aspects of one and the same phenomenon, three mutually exclusive hypotheses are used.

In the present study, the orientation of the arcs is considered from the viewpoint of the spiral distribution of disturbance over the polar cap. It is assumed that the extended linear forms are oriented along the auroral spirals. In this case, the principal features of the diurnal march of the azimuths of the arcs can be explained.

To elucidate the question as to the morning "break" in the azimuths, all available material was analyzed. The data obtained are plotted in Fig.2. Because of the fact that distinct arcs are rarely observed at this time, we present data obtained in working up the all-sky films of several stations (Murmansk, Dikson Island, Tiksi Bay, Vize Island, Piramid Station, and Cape Chelyuskin).

On the same graph, we also give the curves of the diurnal march of the orientation of the spirals (curves 1) and the theoretical curve of Alfven (curve 2)*. The curve 3 is the mean of the experimental data, while the vertical lines show the mean-square errors. The coordinates are geomagnetic. /27

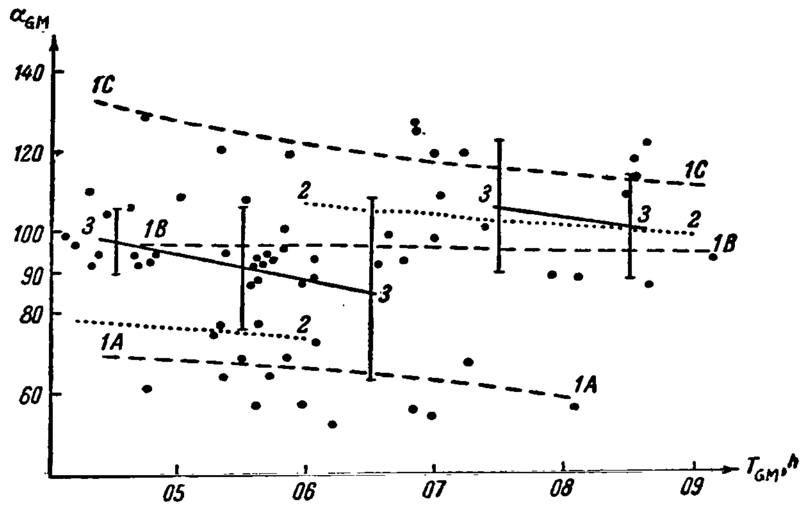

Fig.2

The scattering of the points on the graph is considerable, but the average curve agrees relatively well with the Alfven curve. Still better agreement is observed with the curve of the diurnal march given elsewhere (Bibl.6, 9). In addition, the amplitude of the diurnal march of azimuths, according to Alfven, should be constant although all experimental data give an increase of this amplitude with increasing latitude. The "break" is also shifted to 0700 - 0800 h, instead of 0600 h according to Alfven. With the orientation of the arcs along the spirals, the "break" of the azimuths should not occur at 0600 h but at 0700 - 0900 h, i.e., during the time of the northern intersection of the spirals ($\Phi \approx 78^{\circ}$). Up to this instant, the azimuths of the arcs should decrease, and a maximum scatter should be observed at the time of the break, since the arcs can be oriented along two different spirals (curves 1A and 1C), after which the sharply increasing azimuth again begins a smooth decline (curves 1B and 1C). This is connected with the fact that one spiral runs North from the station while the other, on the contrary, runs toward the station, and that the orientation of these spirals differs. This is the picture that is observed in reality (Fig.2).

The amplitude of the diurnal march of the azimuths of arcs oriented along the spirals should increase with the latitude, and in the region of the geomag-

* We used auroral spirals analogous to the spirals presented elsewhere (Bibl.5). Because of the large number of points, these were prolonged into the region of higher and lower latitudes. The curves 1 were plotted by Starkov's method (Bibl.7) and correspond to these spirals.

netic pole, azimuths up to 180° should be possible. This is confirmed by the experimental data on the diurnal marches of the azimuths in high latitudes. /28 The considerable scattering of the points obtained by all authors is related to the fact that the spirals are the result of averaging numerous data over some period, while their position at each specific instant may deviate considerably

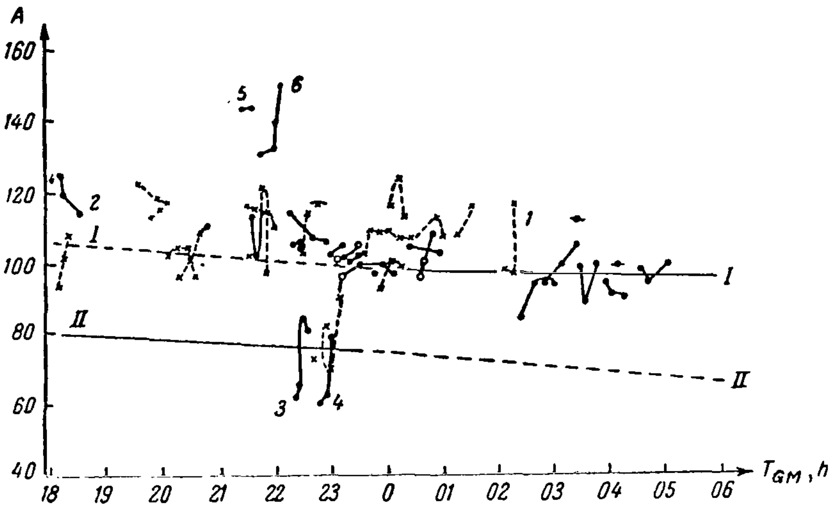

Fig.3

from the mean. The position of the spirals also depends on the magnitude of magnetic disturbance. Further than that, a longitudinal effect is observed, i.e., the spirals for the western and eastern sectors of the Arctic differ in shape. Constructing the spirals in reduced geomagnetic coordinates, i.e., tying them to the position of the zone, will yield a better agreement.

The diurnal march of the azimuths was most fully analyzed for the Murmansk station ($\Phi = 64.1^{\circ}$, $\Lambda = 126.5^{\circ}$). The amplitude of the diurnal march in this case is relatively small, for which reason we noted the geographical position of the arc relative to the station on the spirals. With rare exceptions, we considered only the long-lived arcs (with a life of at least 20 min). Figure 3 gives the azimuths of arcs for Murmansk, the orientation of the spirals being shown by the straight lines. Curve I corresponds to the "night" spiral, while curve II corresponds to the "morning". The dashed line indicates that the spiral should pass North of Murmansk. The dots show the arcs located South of the station, and the crosses those North of it. The data corresponding to one and the same arc are interconnected. The circles refer to zenith displays.

It will be clear from the diagram that, in the absolute majority of the /29 cases, the arcs are grouped about curve I, and the geographical position of the arcs agrees with the position of the spiral. All deviations have to do with the character of the magnetic field. In the absence of magnetic disturbance, or at only a minor such disturbance, the spiral with the aurora is shifted to the north of its mean position, while during an intense storm it is shifted the other way. Thus, the arc of February 25 at 2010 h (arc 1), not accompanied by disturbances, is oriented along the "night" spiral and is located North rather than South. Arc 2, observed somewhat to the south of Murmansk as early as 1800 h, did coincide with the magnetic storm. The southern arcs 3 and 4 fit well on the "morning" spiral and are observed at disturbances of moderate intensity. The arc 5 (January 25) existed for only 7 min and rapidly passed from North to South of the Kola Peninsula; the magnetic station recorded a sharp overshoot of

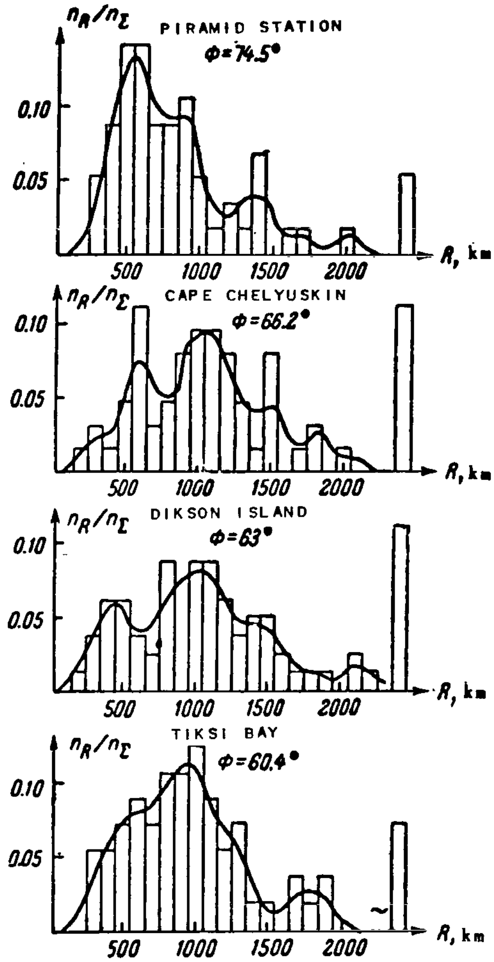

Fig.4

about the same duration. All deviations of the position of the arcs from those of the spirals can be similarly explained. Arc 6 is an exception; this arc was located in the south at a relatively early time of the day and was accompanied by a slight disturbance ($H \approx 80^{\gamma}$, $Z \approx 20^{\gamma}$). The rays without bends, the radial and homogeneous bands are generally oriented in the same way as the homogeneous arcs.

It has been shown (Bibl.7) that the projections of homogeneous arcs as a rule have relatively small radii of curvature. They are considerably shorter than the radii of the main zone and the auroral ring obtained by O.V.Khorosheva (Bibl.13). In this case, we consider the variation in the curve of probability of appearance of arcs with a specific radius as a function of the latitude. /30 Figure 4 gives the curves for four stations. The ratios of the number of arcs with a given radius to the total number of arcs are plotted on the ordinate. We used only those stations for which at least 50 radii were determined. The bars at the ends represent the relative number of arcs with a radius of curvature greater than 2200 km. The very long arcs are usually of considerable radius, equal to, and in some cases even greater than, the radius of the zone.

It will be clear from these bar graphs that the probability curves have two maxima: 500 - 600 km and 1000 - 1200 km. At the high-latitude stations there was one maximum of $R_{max} \approx 550$ km. On approaching the main zone, this maximum decays and becomes almost invisible for Tiksi Bay, but a second maximum appears at $R_{max} \approx 1000$ km. It is interesting that, on variation in the geomagnetic latitude, the maximum does not shift and that there is, instead, a redistribution of the amplitudes of the two maxima. The intermediate cases of distribution are observed at the Cape Chelyuskin and Dikson Island stations. The first maximum is greatest for the stations of the inner auroral zone, while the second corresponds to the principal zone.

The coastal effect plays a certain part in the distribution of arcs by radius. Thus, at Tiksi Bay we observe arcs with a bend along the shoreline, the radius of the overwater part being relatively small. For Tiksi Bay only arcs without a bend were taken into account. For Murmansk, on the other hand, many arcs of radius greater than 2200 km are observed, with a clear influence of the shoreline, which might be said to "straighten" the arc.

The latitudinal march of the distribution of arcs by radius resembles the variation in the radius of curvature of the spirals as a function of the latitude. The radius of curvature of the spirals also decreases with decreasing latitude, but it must be noted that the radii of the projections of the arcs at the maxima are smaller, by factors of 1.5 - 2, than the radii of curvature of the corresponding segments of the spirals.

For each position of the arc, the position of the center of gravity of the current in space was determined from the magnetograms of Murmansk Observatory. The effect of earth currents was taken into account. It is only possible to determine the current from the magnetic field induced by it at a certain point, under the condition that the current is unbounded, horizontal, linear, and direct. Such an assumption as to the ionospheric current is in general very gross. However, near the main zone, at points not more than 600 km from the station and extending 100 km on either side, the current determined from the magnetograms corresponds rather well with the actual current. Y.Sobouty (Bibl.12) showed that near the current, if its width is considered to be 200 km, H and Z differ by 20 - 30% by comparison with the current of the linear field, but this variation of both components has the same sign and does not have an excessive influence on the determination of the direction. /31 The current is considered to flow at a height of 110 km (Bibl.14).

In first approximation, the diurnal march of the azimuths of the currents resembles the march of the azimuths of the arcs, although it is true that the scattering for the currents is still greater. The maximum deviation of the spiral occurs for the currents, both eastern and western, between 2300 h and 0100 h local geomagnetic time, i.e., at the time of intersection of the spirals. In considering specific cases, it was found that as a rule the current and arc do not coincide in space. This agrees with the results obtained by M.I.Pudovkin and L.S.Yevlashin (Bibl.15). Another worker (Bibl.12) obtained the opposite result. In that case, the southern boundaries of the currents and the aurorae coincided, but it must be noted that we did not divide the currents into eastern and western; however, for overall statistics such a result is entirely regular.

t_{GM}	$18-22^h$	$22-02^h$	$02-06^h$
$\frac{n_{\parallel}-n_{\perp}}{n_{\Sigma}}$	0.6	0.4	0.7

The arc and the current often include a relatively large angle. We calculated the ratio of the difference in the number of cases of parallel and nonparallel current and arc to the total number of observations, i.e., $\frac{n_{\parallel}-n_{\perp}}{n_{\Sigma}}$, for three time intervals. The results are given in the Table. The greatest number of cases of nonooincidence occur during the period of local geomagnetic midnight. This interval coincides with the zero point and the instant of intersection of the spirals, so that such noncoincidence is entirely regular. In individual cases, the variation in the azimuth of the current varies like that of the azimuth of the arc. It is interesting that current and arc, in these cases, may include a considerable angle, and this peculiar equilibrium may persist for a rather long time. The amplitude of variation of the azimuth of the arc is always less than the amplitude of variation of the orientation of the current. Three such cases are shown in Fig.5.

For cases in which the arc and current were parallel, their positional angles from the northern horizon were determined. Figure 6 shows these data. On the abscissa we plotted the positional angle of the current, and on the ordinate axis the positional angle of the aurora. The points up to 2200 h for the eastern current are denoted by crosses and, after 2230 h for the western current, by circles. Cases when a current of westerly direction flows after 2330 h are indicated by two concentric circles. If the current and arc would coincide, all points would lie on a straight line making an angle of 45° with the coordinate axes. All the evening points, however, lie below the straight line, and all the morning points above it. This means that up to midnight the current flows to the south of the arc, and after midnight to the north of it. A similar result was obtained elsewhere (Bibl.15). It is also clear that the circles and /32
crosses are not arranged at random but in obedience to some law. In Fig.6, the heavy curves are plotted on the basis of experimental data averaged for each interval of angles.

According to the theory developed by Pudovkin (Bibl.15), such an effect should be obtained on account of the ejection of ions, and consequently of current, from the region of ionization which coincides with the arc. At a certain distance between the center of gravity of the current and the arc, a dynamic equilibrium sets in. For the western and eastern currents, the arithmetic mean of the distance was calculated between the point and the arc Δx, and then this distance, which was considered constant, was used for plotting the curves shown as broken lines. The empirical and calculated curves are in good agreement, and it can therefore be considered that the mean value of the wind is constant for

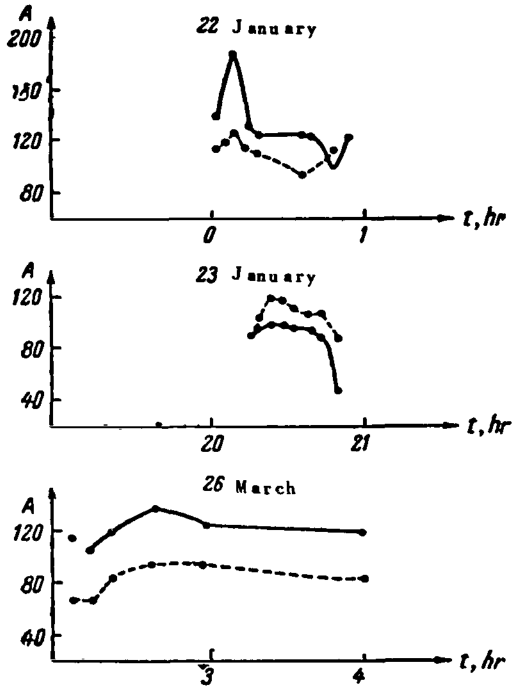

Fig. 5

Broken line: variation of azimuth of arc; heavy line: variation of azimuth of current

the eastern and western currents. For the eastern current (positive magnetic bay), Δx = 240 km; for the western current, Δx = 130 km. Considering (Bibl.16) that the coefficient of recombination is 5×10^{-4} sec^{-1}, we find according to formulas given elsewhere (Bibl.15) that the velocity of the wind of the northern component is 120 m/sec (positive bay), while the velocity of the southern component is 65 m/sec (negative bay). In another report (Bibl.14), where the same current components were calculated, a difference was also found between the northern and southern components (V_N = 180 m/sec, V_S = 120 m/sec). Velocities of the same order, but somewhat higher in value, were obtained. These results are in agreement with other data on the velocity of the wind in the E-layer (see Bibl.17). The points corresponding to currents flowing after midnight from West to East, i.e., not fitting into the general scheme (double crosses) are scattered rather at random. It was found that all these cases agreed with the radial forms of the displays which, in general, are not spatially connected with the currents in the ionosphere (Bibl.15). /33

If we consider the distance between the current and the arc for some time interval, then, according to theory, the arcs should at first deviate from the current but then, after the onset of dynamic equilibrium, the distance between them should no longer vary. In reality such a pattern has never been observed.

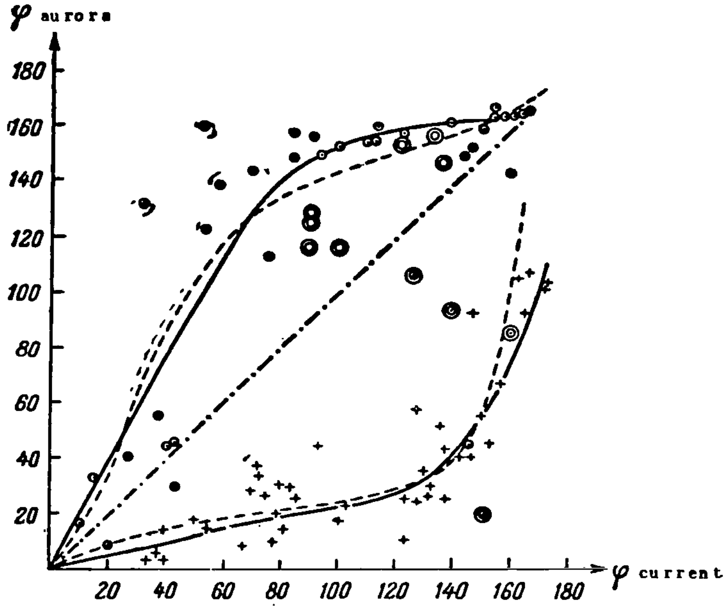

Fig.6

The distance between the current and the arc varies very irregularly, and there have also been cases of reverse motion of an arc relative to the current. This is connected with the fact that these calculations did not take account of the proper velocities of the aurorae themselves, although they may be rather considerable.

CONCLUSIONS

1. The diurnal march of azimuths and the position of arcs may be explained by their orientation along the spiral of maximum probability of the appearance of aurorae. It is possible, from the same viewpoint, to interpret the "morning" break of the azimuths. Most arcs are grouped about the "night" spiral. All discrepancies between the azimuths and the position of the arcs and spirals are connected with the character of the magnetic disturbance.

2. The projections of the radii of curvature of uniform arcs are relatively short. The curves of probability of the appearance of arcs with a given radius have two maxima: R_{max} = 550 km and R_{max} = 1100 km. The first maximum has its /34

greatest value at the stations of the inner auroral zone, the second maximum at the stations of the principal zone. The radius of curvature of arcs at the maxima is smaller, by a factor of 1.5 to 2, than the radii of curvature of the corresponding segments of the spirals.

3. The positions of the centers of gravity of the current and arc do not as a rule coincide. The arc frequently makes a rather considerable angle with the current. This is most frequently observed in the region of local geomagnetic midnight. Before and after geomagnetic midnight, the currents and arcs are, on the whole, parallel. The mean distance between the arc and the western current is about 120 km, and that between the arc and the eastern current is about 240 km. This corresponds to 60 m/sec for the northern component of the wind and 120 m/sec for the southern component. In specific cases, the distance between the current and arc varies rather at random, owing to the proper motion of the aurorae.

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ZONE OF INTRUSION OF THE CORPUSCULAR FLUX AND THE SPIRAL DISTRIBUTION OF THE MAXIMUM PERTURBATION TIME *[/35]

A.B.Korotin

The position and configuration of the target zone of the corpuscular stream, relative to the spiral distribution of geomagnetic disturbance, are defined on the basis of data obtained at 30 points with known geomagnetic coordinates in the polar zone during passage of the auroral ring. The position of the zone depends largely on the intensity of disturbance, showing a closer approach to the Pole at weaker disturbances. An attempt is made to prove that the target zone has a nearly circular shape.

The position of the target zone of the corpuscular flux responsible for the appearance of aurorae and for magnetic disturbances must be defined in the greatest possible detail. The configuration of this zone depends largely on the mechanism of interaction of the corpuscular flux with the earth's magnetic field; consequently, a definition of its true shape will assist in selecting the most logical mechanism from the multitude of those proposed. It is also extremely important to learn the position of the target zone for a number of practical calculations.

In this connection, the work by O.V.Khorosheva (Bibl.1) is very interesting and promising. In this work she establishes a ring-like shape for the target zone. Ya.I.Fel'dshteyn (Bibl.2), showing that the curve of maximum probability of appearance of the aurora versus the local geomagnetic time is of spiral shape, had previously asserted, on the basis of their external similarity, that these zones are oval (i.e., close to circular). However, the spirals obtained by him are merely lines of distribution of the maximum of auroral activity, and their identification with the isochrons still requires special proof, while Khorosheva's rings are the result of direct measurements. Of particular significance is the fact that the target zone is established directly from photographs of the aurorae, and that the aurorae are still the only visible traces (visible in the literal sense of the word) of the influence of the corpuscular flux on the upper atmosphere of the earth.

In this article, we will discuss the results of investigations in connection with previously obtained data. Here and later we will understand the term "target zone" to mean the projection, onto the earth's surface, of that part of the celestial vault in which, at a given hour of the day, an aurora display can be observed. The aurorae may occupy either the entire zone or only part of it. In particular, the auroral forms may be separated by darker intervals.

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Annular Target Zones and Spiral Distribution of the Disturbance Maxima

/36

Certain features of the target zone may today be considered as established, for example, its movement above the earth's surface during the course of the day. The most general characteristics of this motion were established by O.A. Burdo (Bibl.2) for the magnetic disturbances, and by Ya.I.Fel'dshteyn (Bibl.3)

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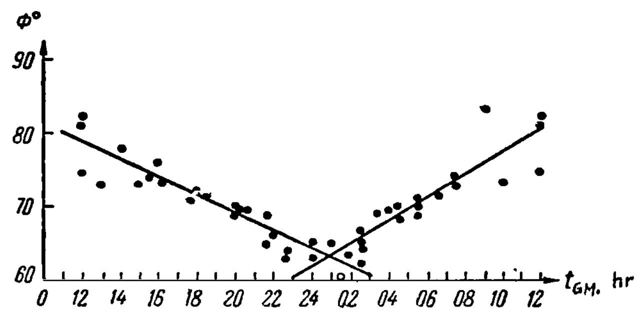

Fig.1

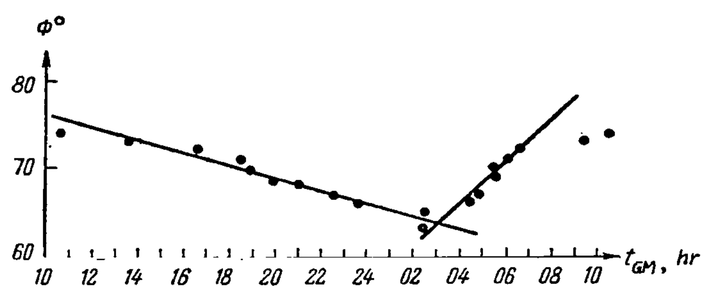

Fig.2

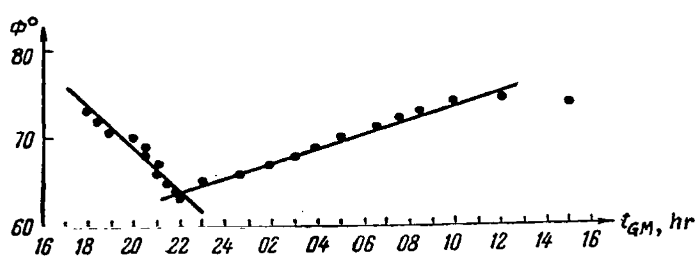

Fig.3

for the aurorae. These authors found that the maximum of disturbance at a given geomagnetic latitude occurs at a definite geomagnetic time. It is true that the laws for the magnetic disturbance and the aurora are somewhat different. These relations, in rectangular coordinates, are represented by two straight lines, but in polar coordinates by two spirals turning in opposite senses. Obviously any model of the target zone and its displacement over the earth's surface must be such as to satisfy the above laws.

To verify this, 30 points with known geomagnetic coordinates were selected in the polar zone and the passage of the ring (according to Khorosheva) over these points was considered. The points were so selected as to be distributed more or less uniformly over the polar region, including the zone of maximum frequency of occurrence of auroral displays. The time of the maximum frequency was considered to be the time of passage of the ring over the point, or the time when the ring was closest, if it did not pass over the point. Figure 1 shows the geomagnetic time of the maximum (t_{GM}) as a function of the geomagnetic latitude of the point, Φ. It will be immediately clear that the required relation

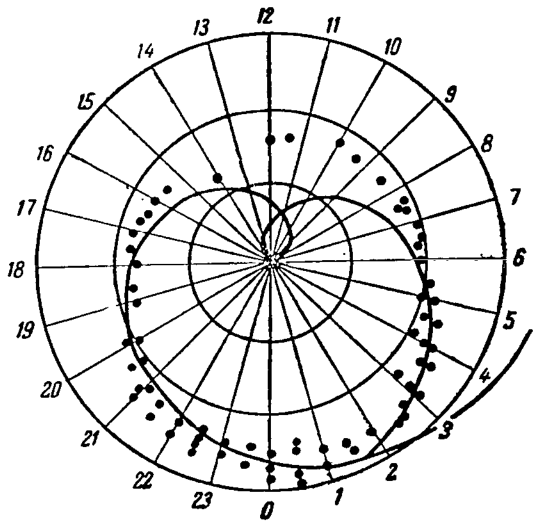

Fig.4

is of the same character as the relation obtained by Ya.I.Fel'dshteyn, i.e., a relation that is a so-called spiral (in polar coordinates), which speaks in favor of the model proposed by O.V.Khorosheva. It should be noted, however, that the spirals so obtained were plotted at points more or less uniformly distributed over the polar zone. If we study the motion of the aurora in a narrow sector (for example, along a single geomagnetic meridian), the picture may be substantially distorted. The above is demonstrated in Fig.2 (motion of the aurorae along the Murmansk meridian Λ = 126.5 E) and Fig.3 (College Meridian Λ = = 103.4 W). The spirals in both graphs are asymmetric, and one graph is almost a mirror image of the other. This result is essential in comparing the calculated and experimental spirals. It would be desirable in general to plot them for several points.

In a direct comparison of the calculated spirals with the spirals of Ya.I. Fel'dshteyn plotted from data of a station in the Eastern Hemisphere, points located in the same hemisphere were selected. The spirals of Ya.I.Fel'dshteyn and the points calculated from the rings are shown in Fig.4. The results are in satisfactory agreement up to latitude 70 - 72°, but certain discrepancies are noted in the higher latitudes. We do not know whether these discrepancies are connected with the deformation of the ring or with the expansion of that part of it closest to the geomagnetic pole. Moreover, the influence of a certain effect, not taken into account by O.V.Khorosheva, is possible. We mean that /38 the position of the target zone depends largely on the intensity of the disturbance. In this connection, it was of interest to measure the position of the target zone during a weak disturbance, when the second zone of maximum auroral frequency is distinctly manifest. It is possible that, in this case, the aurora approaches closer to the Pole, since the diameter of the target zone is known to be smaller.

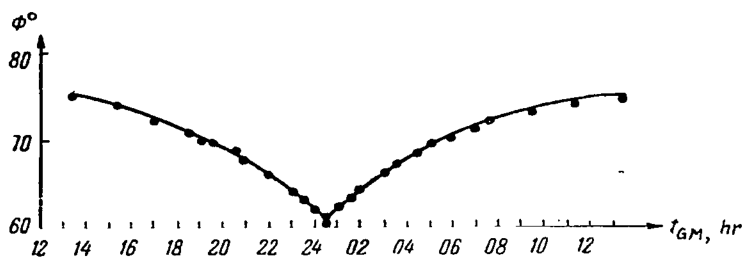

Fig.5

Figure 5 shows spirals plotted for the 180° meridian. The special slope of the curves is noteworthy. It would be interesting to compare them with the experimental data.

Annular Target Zones and Magnetic Disturbances /39

To verify her conclusions, O.V.Khorosheva attempted to use magnetic data. As was to be expected, the magnetic disturbances and the auroral isochrons are far from always agreeing, especially in the polar zone, frequently requiring reservations as to possible discrepancies. Here, the point is that the aurorae actually determine the site of arrival of the corpuscles, whereas the magnetic disturbances still do not mean that the corpuscular flux actually does strike the given location.

It is well known (Bibl.4) that the currents arising in the auroral zone are closed across the polar cap. These currents naturally cause disturbances in the cap. An indirect confirmation of this is the fact that the magnetic disturbances are very often unaccompanied by aurora (Bibl.5). Moreover, as shown elsewhere (Bibl.6), the corpuscular flux alone would be insufficient to produce the current in the upper atmosphere; it merely increases the conductivity of that atmosphere. The emf inducing the current may have its own diurnal march, which may lead to the appearance of additional maxima totally unrelated to the ring.

The discrepancies that may arise as a result of these (and perhaps also other) causes are so great that the isochrons of the aurorae (the ring actually is an isochron) and those of the magnetic disturbance [the spirals of A.P.Nikol'

skiy (Bibl.7)] are completely dissimilar. Further than that, each of them /40
speaks in favor of entirely different physical mechanisms of interaction between the corpuscular flux and the earth's magnetic field.

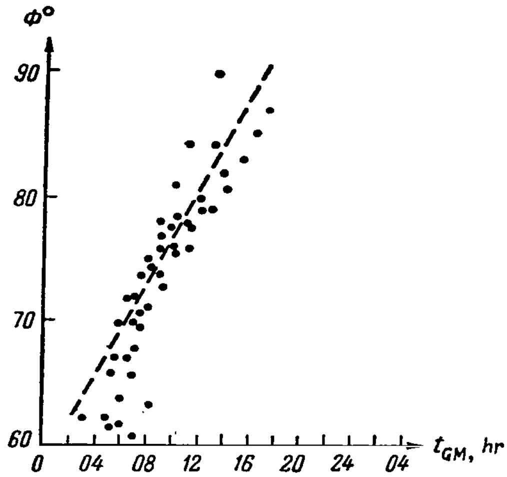

Fig.6

It should be noted that the A.P.Nikol'skiy spirals correspond to the laws established by O.A.Burdo. The points in Fig.6 are taken from the A.P.Nikol'skiy spirals and converted into the corresponding coordinates: Φ', reduced geomagnetic latitude; t_{GM}, local geomagnetic time; the broken line in the graph is the "morning" spiral described by O.A.Burdo. The excellent agreement is not unexpected, since the authors used the very same data but different coordinates.

It should also be noted that spirals analogous to those of O.A.Burdo can be obtained, as already stated, by starting out from the annular target zone. It is apparently also possible to have other forms of the target zone. In this connection, the "spirality" of the O.A.Burdo curves cannot serve as an argument for the spirality of the target zone.

CONCLUSIONS

1. The annular target zone proposed by O.V.Khorosheva is in rather clear agreement with earlier statistical data. This fact, together with other data (Bibl.1), seem to indicate that the shape of the target zone is close to circular.

2. Certain discrepancies in the upper latitudes require refinement of the position of the target zone. The intensity of the disturbance during the measurements of the position of the ring must be taken into account.

3. The difference between the diurnal marches of the magnetic disturbance and the data resulting from the position of the target ring cannot serve as an

argument against those data.

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SHORT-PERIOD FLUCTUATIONS IN THE GLOW INTENSITY OF POLAR AURORAE AND THEIR ASSOCIATION WITH GEOMAGNETIC PULSATIONS *<u>/41</u>

R.G.Skrynnikov and V.P.Selivanov

Short-period fluctuations in auroral brightness in their correlation with geomagnetic pulsations are calculated on the basis of electrophotometer (180°) recordings of auroral flashes in integral light and in the emissions of λ 3914 Å and λ 5577 Å. Comparison with simultaneously recorded pulsations of the geomagnetic field, at a scanning rate of 12 and 20 mm/min, showed characteristic fluctuations of 4 - 8 sec period with a shortening of the mean period toward the morning hours (local time). The mean diurnal march of the amplitudes showed an evening maximum at 1900 GMT and a midnight maximum at 2300 GMT. The correlation between auroral flashes and geomagnetic pulsations is explained on the basis of the dynamo theory of ionospheric winds.

At the Geophysical Station Lovozero ($\varphi = 67° 59'$, $\lambda = 35° 05'$) in 1961 - 1963, staff members of the Polar Geophysical Institute and of the Department of Earth Physics, Leningrad State University, made observations on the aurora by the aid of a 180° electrophotometer with plane photocathode directed to the zenith. At the same time, the short-period fluctuations of the earth's magnetic field were recorded by several modified Brunelli magnetic microvariation stations. This apparatus has already been described elsewhere (Bibl.1, 2). The 180° electrophotometer registered the integral light flux of the aurora. The variations in auroral intensity were recorded in the emissions λ 3914 Å and λ 5577 Å by means of a mirror system by the C-180 camera; the light flux reflected from the mirrors and passing through a filter, which lets pass only the light of the emission in question, was registered by an FEU-19M photomultiplier.

The electrophotometer was calibrated against the moon; one scale division of the channel of the record of the 3914 Å emission was 0.8×10^{-12} w/cm²/mm; a scale division of the recording channels for the 5577 Å emission was 2.5×10^{-12} w/cm²/mm.

In the present work, we are analyzing the electrophotometer records of the short-period fluctuations (SPF) or "flashes" of the aurora in integral light and in the emissions λ 3914 Å and λ 5577 Å, together with the analysis records of the pulsations of the geomagnetic field at a scanning rate of 12 and 20 mm/min. Examples of the record of the SPF of the auroral light flux are given in Figs.1a and b where 1 is the SPF record of the emission 3914 Å; 2 is the SPF record of the emission 5577 Å; 3 (in Fig.1a) is the SPF of the integral light; 3 (in Fig.1b) is the record of the pulsations of the geomagnetic field. A comparison

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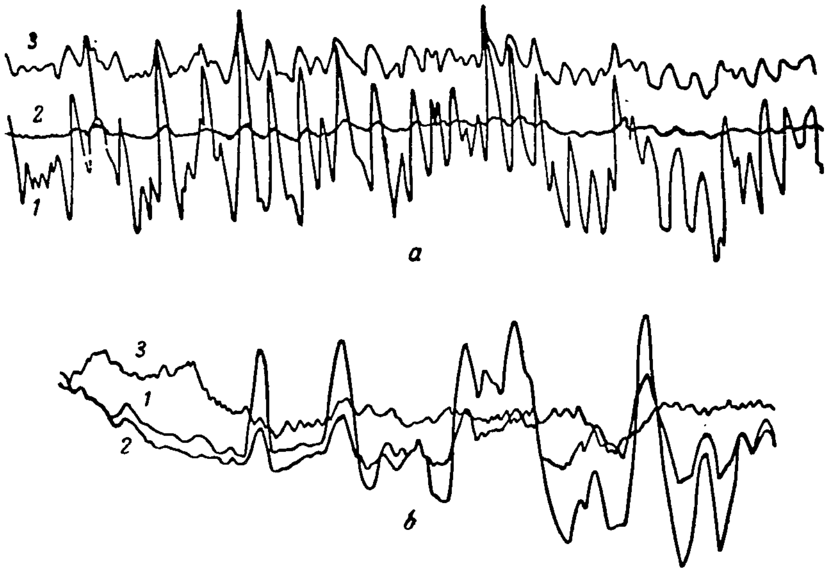
3
2
1
a
3
1
2
б

Fig.1

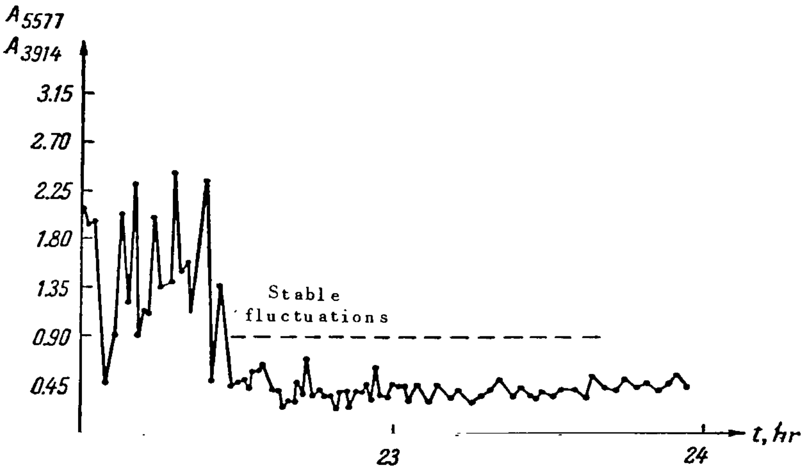
A_{5577}
A_{3914}
3.15
2.70
2.25
1.80
1.35
0.90
0.45
Stable fluctuations
23
24
t, hr

Fig.2

of the records of the "flashes" in integral light and in the emissions shows /43 that the peaks of the auroral variations, recorded in integral light, coincided almost completely with the peaks of the 3914 Å emission. This is readily explained by recalling that the maximum sensitivity of the FEU-19M photocathode is at 3900 Å, while the photomultiplier is 4 - 5 times less sensitive up to the line 5577 Å, and after 6000 Å almost completely loses its sensitivity. A comparison of the individual SPF peaks of the aurora in the emissions shows a lag of the 5577 Å emission peaks relative to the 3914 Å emission peaks, whereas the glow in the 5577 Å emission peak continues for a certain time after the 3914 Å emission has stopped.

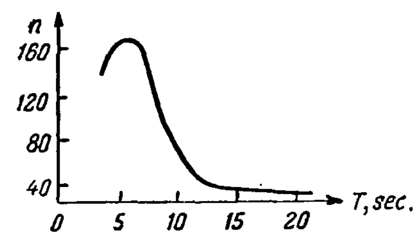

Fig.3

The amplitude ratio of the corresponding peaks of the "flashes" in the emissions is not constant during development of the auroral display. Figure 2 is an example of the amplitude ratio of the "flashes" in the emissions. The amplitude of each emission is expressed in watts. The ratio varies by a factor of 4 - 5 from peak to peak. The variations are particularly great at times when the SPF fluctuation of the aurora in unstable. When the fluctuations become stable, i.e., have about the same periods and amplitudes, the amplitude

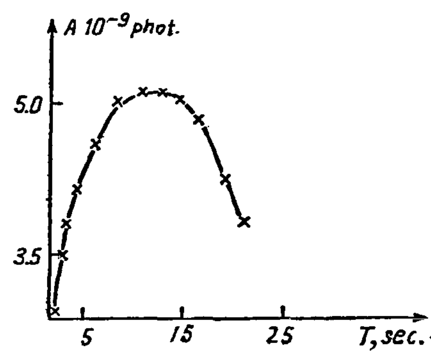

Fig.4

ratio of the "flashes" also becomes stabilized. The amplitude ratio of the emissions (expressed in watts) at the beginning of a display is on the average 1.35, or (expressed in kilorayleighs) 1.9, in agreement with the ratios given by M.Rees (Bibl.2). Later, however, this ratio becomes 0.45 (in watts) or 0.6 - 0.7 (in kilorayleighs). The latter ratio holds exactly at the time when the fluctuations become stable (2300 - 2400 h GMT). The comparison of the individual peaks was supplemented by a statistical work-up of the results of observation of the "flashes".

We considered certain morphological features of the short-period fluctuations of auroral intensities. The fluctuations were arbitrarily divided, according to period, into four groups: 1) 4 - 8 sec; 2) 9 - 13 sec; 3) 14 - 18 sec; 4) over 18 sec. In Fig.3, the frequency of appearance of SPF of the auroral light flux of various periods is plotted, according to observations at Lovozero. /44

The term "frequency of appearance of SPF" was taken to mean the number of peaks of different periods registered during the course of a display, and of peaks having amplitudes three or more times greater than the ordinary background (but not the night sky) observed at times without disturbance. The diagram shows that light flux fluctuations of a period of 4 - 8 sec are most frequent, in agreement with the data of other authors (Bibl.1, 2, 4, 5). The number of fluctuations with a period of 6 sec is ten or more times larger than the number of fluctuations with a period of 25 sec, and four times larger than the number of 12 - 14 sec period fluctuations.

A graph for the correlation of the amplitude of these fluctuations with their period (Fig.4) exhibits one wide maximum, with the fluctuations having a 12 - 14 sec period showing the greatest amplitude (1.5×10^{-8} phot).

The amplitude of the 6-sec fluctuations and of the 20-sec fluctuations is less by a factor of 1.5 than the amplitude at T = 13 sec. The diurnal march of the SPF amplitude of auroral display brightness (S_A) is shown in Fig.5, where the 4 - 8 sec periods are represented by curve 1; the 9 - 13 sec periods by curve 2; the 14 - 18 sec periods by curve 3; the 18 sec periods by curve 4; and the average for all periods by curve 5.

To construct S_A from the electrophotometer records, we made hourly measurements of the SPF amplitudes of auroral intensity for each period. We then calculated the mean amplitude for each group of fluctuations for each hour, and defined its ratio to the maximum amplitude of the corresponding group. To construct the mean diurnal march, we calculated the mean amplitude for each hour for all periods and then determined the ratio of A_{av} to the maximum amplitude. All curves of the diurnal march show two maxima, one at 1900 - 2000 h and one at 2200 - 2300 h GMT.

The diurnal march of the frequency of SPF appearance of auroral intensity of various periods (abbreviated S_T) is shown in Fig.6, where the symbols 1 - 5 have the same meaning as in Fig.5. The evening maximum for all groups occurs at 1900 h GMT, whereas the midnight maximum for the first group takes place at 2300 h for the second group at 2200 h, and for the third and fourth group at 2100 - 2200 h GMT. The march of the mean curve of S_T resembles the march of S_A, both maxima of the curves S_A and S_T occurring at approximately the same time: in the evening at 1900 - 2000 h and at midnight at 2200 - 2300 h GMT.

Mitra (Bibl.6) gave the diurnal march of the frequency of appearance of /45 various auroral forms on the basis of visual observations in 1961 - 1962 at Murmansk, which is 140 km NW of Lovozero. A comparison of S_T and S_A with the diurnal march of frequency of appearance of all auroral forms (Fig.5, curve 6) and the radial forms (Fig.5, curve 7) clearly shows that the maxima of S_A and S_T

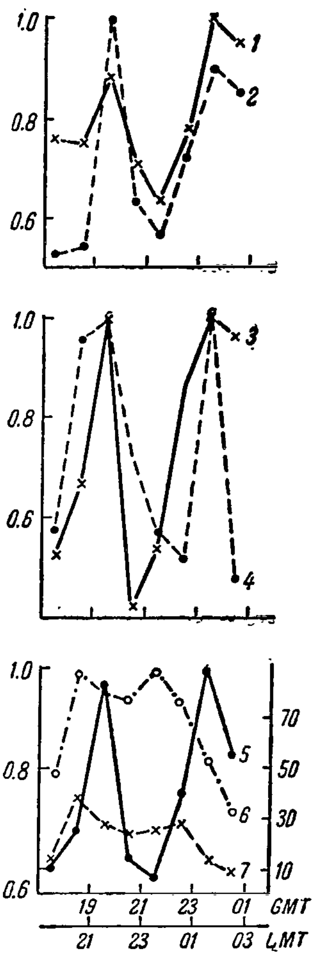

Fig.5

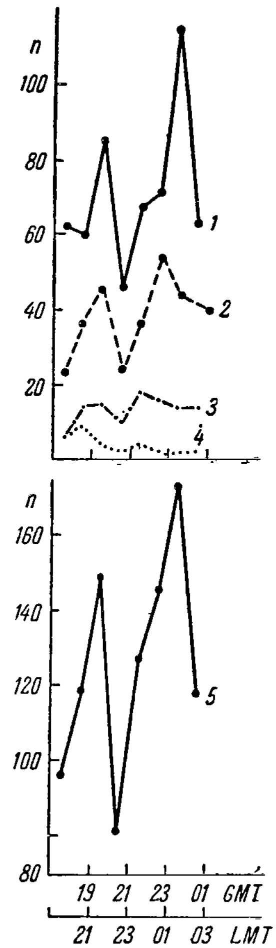

Fig.6

occur one hour later than the maxima of the diurnal march of the radial forms and all other auroral forms. It is obvious from a comparison of S_T with the diurnal march of the frequency of appearance of the individual auroral forms that, in slope, the diurnal march of the radial active forms of the aurora agree most closely with S_T. /46

The maxima in the diurnal march of the frequency of appearance of the "flashes" lag one hour relative to the maximum of frequency of auroral display.

In Fig.7, the period of the intensity SPF, calculated as the arithmetic mean for each hour of the day, is plotted on the ordinate. The time of day

(GMT) is plotted on the abscissa axis; on comparing it with Fig.6, we note the existence, in the maxima of frequency of auroral appearance (1900 h and 2200 h GMT), of a large number of long-period fluctuations of intensity (12 - 14 sec) and a shortening of the mean period after each maximum, i.e., an increase in the number of short-period flashes (4 - 6 sec) at 2000 h and in the pre-dawn hours (after 2300 h GMT).

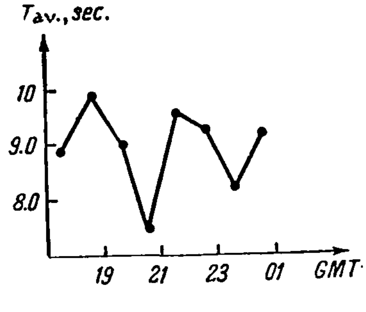

Fig.7

It should be noted that, on appearance of the aurorae, "flashes" of longer periods usually occur and that, with the passage of time, the number of short-period "flashes" increases; this number increases still more during break-up and disappearance of the aurorae. If the "flashes" or SPF of the light flux of the aurora are explained by the structural inhomogeneity of the influx of solar particles, then one must recognize that the principal dimension of the micro-inhomogeneity of the flux associated with the "flash" should be equal to $-\lambda$ = = UT - |2 - 3| • 10^8 cm, since the principal period is 6 sec and the velocity of the flux is 300 - 500 km/sec (Bibl.7).

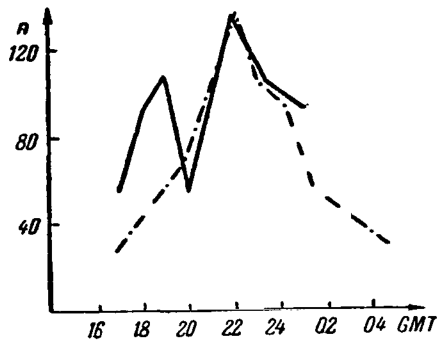

Fig.8

Simultaneously with the record of the "flashes", the pulsations of the geomagnetic field were also recorded. Rees (Bibl.2) noted the appearance of "pearly" formations in the absence of auroral displays. In 1961 - 1963, at such times, extreme pulsations of a nearly sinusoidal form were observed, while irregular pulsations as a rule occur together with the aurora.

Figure 8 gives a graph of the frequency of appearance of geomagnetic SPF of the Sip type (dot-dash line) and a graph of the frequency of appearance of the "flashes" of the aurora S_T (broken line). The following is noted on comparison of these two graphs. /47

1. The increase in the number of "flashes" at 2000 - 0100 h GMT causes an approximately proportional increase in the number of geomagnetic SPF of the Sip type.

2. The evening maximum of the "flashes", at 1800 - 2000 h GMT, is not connected with the corresponding proportional increase in the geomagnetic SPF. From the viewpoint of the dynamo theory this fact can be explained as follows: At 1800 - 2000 h GMT, the meridional component of the ionospheric wind reaches a minimum, so that also $E = \frac{1}{c}$ [VH], the field of polarization, shows a minimum. Here, the velocity vector of the ionospheric wind is directed along the target zone of the solar particles in the zone of the aurorae (Bibl.8).

However, in view of the fact that, at 1800 - 1900 h GMT, the irregular SPF of the geomagnetic field do not completely disappear and that there are a series of irregular peaks of small amplitude and duration at the intermediate point between the positive and negative bays, it could well be that, together with the regular mean diurnal motion of the velocity vector of the ionospheric wind, there also exists a random motion producing a rapidly varying meridional component of the velocity vector. The magnitude of this velocity component of the ionospheric wind may reach 20% of the maximum velocity of the wind.

The presence of irregular motion in the ionosphere is qualitatively confirmed by studies of the drifts of ionospheric irregularities by radio methods (Bibl.7, 9, 10). It is easy to calculate that a variation of 20% corresponds to a 10° rotation of the wind velocity vector away from the direction of the target zone. At the minimum (1800 - 1900 h), this induces a proportional 20% variation of the field since $\Delta V_{merid} = V_{max} \cdot \sin\alpha \approx V_{max} \cdot \alpha$, whereas at the maximum (2200 - 2400 h GMT), such a change will produce only a 2% variation in the field, since then $\Delta V_{merid} = V_{max} - V_{max} \cdot \cos\alpha$.

Thus, the variations in the geomagnetic field are related in about the same way to the variations of conductivity in the ionosphere and to the variations of the ionospheric wind. Let us determine the rate at which the polarization field $E_p = \frac{1}{c}$ [VH], due to the ionospheric wind, will vary when the wind varies from V_0 to 0 or, in other words, let us calculate the characteristic time of disappearance of the polarization field on instantaneous disappearance of the wind.

Let us consider that the velocity of the wind is V_0 at $t \leq t_0$ and zero at $t > t_0$. Let us write the equations for the correlation between current, charge, and field in the medium:

$$\nabla j + \frac{1}{c}\frac{\partial \rho}{\partial t} = 0; \; j = \sigma E$$
$$\nabla E = 4\pi\rho.$$

Substituting ∇j and $\frac{\partial \rho}{\partial t}$ by their expressions in terms of E, we find that $E = E_0 e^{\frac{t}{\tau}}$, i.e., the field declines exponentially, and the characteristic time of decline will be $\tau = \frac{1}{4\pi c\sigma}$, where σ denotes the conductivity of the ionosphere. At $\sigma = 10^{-12}$ CGSM, the characteristic time is 2.5 sec, i.e., the polarization field varies practically with the variation in wind.

CONCLUSIONS

1. For the short-period fluctuations of auroral brightness, fluctuations with periods of 4 - 8 sec are most characteristic.

2. The principal dimension of a microinhomogeneity in the influx of solar particles is of the order of $(2 - 3) \cdot 10^8$ cm.

3. The maximum amplitude is found in fluctuations with a period of 12 - 14 sec.

4. The mean diurnal march of the amplitudes and the overall diurnal march, by periods, of the SPF of auroral intensity have an evening maximum at 1900 h GMT and a midnight maximum around 2300 h GMT.

5. For the mean period of these fluctuations, we note a shortening toward the morning hours, by local time.

6. The amplitude ratio of the "flashes" in the emissions varies during evolution of the display.

7. The correlation between auroral "flashes" and pulsations is explained by certain propositions of the dynamo theory.

8. The existence of a random rapidly varying motion of the velocity vector of the ionospheric wind is postulated.

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DETERMINATION OF THE PARAMETERS OF THE DISTURBED IONOSPHERE IN THE ZONE OF POLAR AURORAE */49

M.I.Pudovkin

Ionosphere anomalies, in their influence on the intensity of polar aurorae, were investigated on the absorption of cosmic radioemission during geomagnetic storms at a frequency of several tens of megacycles. Formulas are derived for calculating the absorption of radio noise, linear density of the ionospheric electric current, and the intensity of magnetic disturbance to demonstrate the close correlation of magnetic disturbance and brightness of auroral display.

One of the most important problems of the physics of the upper atmosphere is to investigate the state of the disturbed ionosphere and the microprocesses taking place there (ionization, recombination, etc.). The methods of investigating the ionosphere from ground radio-ranging stations, which are in wide use, generally were inapplicable in our case because of the anomalous absorption of radio waves during magneto-ionospheric disturbances, i.e., at precisely the time when the processes under investigation take place. A direct investigation of the upper atmosphere during geomagnetic storms by means of rockets certainly yields extremely important information on its state, but in view of the great expense of such experiments, they can be performed only on a very limited scale. For this reason, the studies of the absorption of cosmic radio noise at a frequency of several tens of megacycles, which have become very popular during the last few years, are of considerable interest, for they permit determination of the integral absorption of radio waves in the ionosphere during a geomagnetic storm of any intensity (Bibl.1, 2, 3, 4, 5). Without the use of other geophysical observations such studies are not sufficiently comprehensive for an accurate localization of this absorption in some specific layer of the ionosphere, which would permit a more or less reliable determination of the density of ionization, the frequency of collisions, and other parameters of the absorbing layer.

In the modern literature, the anomalous absorption of radio waves is most often assumed to take place in the D-layer, i.e., at or below a height of the order of 80 km (Bibl.5, 6). It is true that several papers (Bibl.7, 8) have recently been published in which attention is directed to the fact that the E-layer, under certain conditions, may also furnish a certain contribution to the total absorption. However, a number of facts indicate that the absorption of radio waves during the night hours of the winter months takes place primarily in the E-layer. According to current concepts, the ionization of air molecules /50
in the upper atmosphere and their optical excitation are due to the same particles that invade the ionosphere (Bibl.9, 10), and the rate of ionization is pro-

* Numbers in the margin indicate pagination in the original foreign text.

portional to the intensity of the aurorae (Bibl.10, 11, 12). At the same time, the height distribution of auroral brightness (Bibl.13), and expecially of such forms as the homogeneous and diffuse arches, which are most closely connected with magnetic disturbances, would indicate that most of their energy is lost through the corpuscular streams at a height of about 100 km, in a rather narrow layer 10 - 20 km in thickness. It may therefore be assumed that the electric currents flowing in the regions of elevated ionization, and causing geomagnetic disturbances, coincide spatially with the absorbing layer. It is exactly this fact which explains the associated movement of the current layer in the region of anomalous dispersion, noted elsewhere (Bibl.14).

Korotin (Bibl.11, 12) showed that the maxima of intensity of magnetic disturbance lag relative to the maxima of luminosity of the aurorae by an average time, τ = 3 - 10 min. The amount of this lag depends on the recombination rate, and is

$$\tau = \frac{1}{2\alpha N},$$

where α is the effective coefficient of recombination, and N is the ionization density.

However, it was shown (Bibl.8) that the absorption peaks likewise lag 1 - 10 min with respect to the peaks of auroral brightness. This agreement between the parameters of the current layer and the absorbing layer likewise confirms the hypothesis that these layers coincide.

The correctness of this hypothesis is still further confirmed by the results (Bibl.8) of simultaneous observation of absorption from measurements of cosmic radio noise intensity and from the data of a ground ionospheric station. During two aurorae considered there, the absorption below the reflecting layer (E_s), i.e. in the D-layer, did not exceed 10% of the total absorption (assuming in the calculations that the absorption in the nondeflecting region is inversely proportional to the square of the frequency).

Thus, there are a number of data indicating that, during geomagnetic disturbances in the night hours of the winter months, the absorption of radio waves takes place in the current layer. This permits us to combine the data on the state of the ionosphere obtained from an analysis of the geomagnetic variations with the results of measurements of the intensity of the cosmic radio noise and the auroral brightness, which offers interesting possibilities for investigation of the disturbed ionosphere.

The absorption of radio noise on the frequency f_{nc} in decibels is /51

$$A\,\mathrm{db} = 0.46 \int_0^\infty \frac{N\nu}{(2\pi f)^2 + \omega^2}\, dh,$$

where ω is the angular velocity of the electrons. Setting the thickness of the absorbing layer so small that the quantity N and ν in this layer can be considered constant and equal, respectively, to the mean values $\bar{N}$ and $\bar{\nu}$, and remembering that $f \gg \omega$, we obtain

$$A \, \mathrm{db} = 0.46 \frac{1}{f^2} \bar{N} \bar{\nu} \Delta h. \tag{1}$$

In turn, the linear density of the electric current of the ionosphere (i.e., the current flowing across a transverse area of base 1 cm and height Δh equal to the thickness of the current layer) is known to be (Bibl.14)

$$j = \frac{\delta H}{0.2 \operatorname{arc} \tan \Theta},$$

where δH is the intensity of the magnetic disturbance, in oersteds, and Θ is the angle subtended by the current layer at the point of observation. Measuring the current density in CGSE units, and δH in gammas, posing [according to (Bibl.14)] $\Theta \simeq \frac{2}{3} \pi$, and assuming that the observed intensity of the magnetic disturbance in consequence of the earth currents is equal to 3/2 of the value induced directly by the ionospheric current, we obtain

$$j = 4.8 \cdot 10^4 \delta H^{\gamma}.$$

On the other hand, the intensity of the electric current, regardless of the mechanism of its excitation, is

$$j = \bar{N} e \bar{U} \Delta h,$$

where $\bar{N}$ is the ionization density, e is the charge of an electron, and $\bar{U}$ is the mean drift velocity of the electrons along the current belt. Hence

$$4.8 \cdot 10^4 \delta H^{\gamma} = \bar{N} e \bar{U} \Delta h. \tag{2}$$

The value of $\bar{U}$ can be measured by means of radar (Bibl.15, 16, 17).

The system of equations (1) and (2) permits determining the quantities $\bar{N}$ and $\bar{\nu}$ during a magnetic storm of any intensity from observations of A, in db, δH^{γ} and $\bar{U}$, with no assumptions whatever as to the mechanism of excitation of the electric currents in the ionosphere. However, radar studies of auroras are being conducted at considerably fewer points than magneto-ionospheric observations. The value of $\bar{U}$ is therefore far from always amenable to measurement. This difficulty can be avoided if we remember that the electric currents in /52 the ionosphere responsible for the magnetic bays are caused by the dynamo action of ionospheric winds (Bibl.14, 18, 19). In this case, if we assume that the region of more intense ionization is in the form of a belt having a length much greater than its width, then, as shown by Cole (Bibl.19), the velocity of drift of ionization along the current belt ($\bar{U}$) and the velocity of drift of the entire belt in the direction perpendicular to it (V) are correlated by the equality

$$\bar{U} = \frac{\omega}{\nu} V. \tag{3}$$

The magnitude of the velocity can be estimated from the rate of displacement of the currents responsible for the magnetic bays, based on the magnetic data (Bibl.20) at any geomagnetic observatory near the auroral zone.

It follows from eqs.(1), (2) and (3) that

$$\bar{\nu} = \sqrt{7 \frac{A\,\mathrm{db} \cdot f^2\, mc \quad V}{\delta H^{\gamma}} \cdot 10^3}, \tag{4}$$

$$\bar{N}\Delta h = \sqrt{11 \frac{A\,\mathrm{db} \cdot \delta H^{\gamma}}{V} f^2 \; mc \; \cdot 10^{10}}. \tag{5}$$

Equations (4) and (5) permit to determine the value of $\bar{N}$ and $\bar{\nu}$ from the data of any available equipment, such as a magnetic variation station or equipment for measuring the intensity of cosmic radio noise.

Let us verify these formulas on a specific example and consider how the results obtained agree with present ideas on the structure of the ionosphere.

As shown by other authors (Bibl.21, 22), the ionosphere possesses maximum conductivity at the height where $\frac{\omega_e}{\nu_e} = 20 - 30$, i.e., ν_e (frequency of collision of electrons with air molecules) is $(2 - 3) \times 10^5$, and corresponds to a height of 95 - 100 km. It is natural to assume that, at this same height, the currents causing the geomagnetic disturbances also flow. It is therefore to be expected that, if the proposed formulas are correct, the calculated values of ν_e should be close to $(2 - 3) \times 10^5$.

The following data were given previously (Bibl.8):

March 12,1959, 2200 h Moscow time. Absorption of radio noise on frequency 31 mc was 2.5 db. Judging from the magnetogram of Murmansk Observatory for that day, $\delta H^{\gamma} = 175^{\gamma}$; assuming (Bibl.22) that $V = 3 \times 10^3$ cm/sec, we find $\bar{\nu} = 5.4 \times 10^5$; $\bar{N}\Delta h = 3.8 \times 10^{11}$ which, for $\Delta h = 10$ km, gives $N = 3.8 \times 10^5$.

March 28,1959, 2200 h Moscow time. A db = 3.5 db, $\delta H^{\gamma} = 550^{\gamma}$. Hence $\bar{\nu} = 3.6 \times 10^5$, $\bar{N}\Delta h = 8.2 \times 10^{11}$ or, for $\Delta h = 10$ km, $\bar{N} = 8.2 \times 10^5$.

The resultant values of $\bar{\nu}_e$ agree in order of magnitude with those to be expected and differ from them by not more than a factor of two. The calculated value of the electron density is likewise in good agreement with the literature. Moreover, from eq.(3) we can calculate the velocity of the electron drift along the conductivity zone: /53

$$U = \frac{\omega}{\nu} V = \frac{8 \cdot 10^6}{4 \cdot 10^5} 3 \cdot 10^3 = 600 \text{ m/sec},$$

which is likewise in good agreement with the results of direct measurement of this quantity.

Thus, the above formulas would appear to give values of N and ν that are rather close to the real values, and the proposed method of investigating the disturbed ionosphere presumably will find practical application.

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BACK-SCATTER SOUNDING OF THE IONOSPHERE AT MURMANSK *[/54](#)

G.P. Tsirs

The method of ionosphere sounding by back-scattering of short waves from the earth's surface is reviewed, in its application to determine the skip zone of various ionosphere layers under both summer and winter conditions. Perturbations of the ionosphere were measured from distances of up to 2000 km, thus permitting a fairly accurate determination of the maximum usable frequency for radio communication. Auxiliary use of vertical soundings at certain control points of the route is recommended for cases of several reflecting layers.

This paper gives some results on back-scatter sounding of the ionosphere at Murmansk in the direction Murmansk - Rugozero - Leningrad, which are compared with data of vertical sounding at the same points.

The modes of interpretation of the oscillograms of back-scatter soundings are considered, as well as the possibility of using them for determining the skip zone (dead zone) for various layers of the ionosphere. We obtained satisfactory agreement of the data of back-scatter and vertical sounding for both E- and F1-layers under summer ionosphere conditions and for the F2-layer under winter conditions.

Scatter sounding of the ionosphere (SS) using the phenomenon of the back-scattering of short waves by the earth's surface, was being used as early as 1949 in the USSR for determining the maximum useful frequencies (MUF) for short-wave radio links (Bibl.1, 2). In the 50's, the SS method became popular in many countries, as a method of investigating the ionosphere and radio-wave propagation (Bibl.3 - 6).

One of the attractive features of this method is that it permits investigation of the state of the ionosphere over regions far from the point of observation, where there are no vertical sounding (VS) stations. In this connection, in the published work on SS, the results of SS and VS on a single section were by no means always comparable, although such comparison would be of great interest, since it would permit a judgment on the accuracy of the particular method of observation or of calculating the parameters of propagation (MUF, skip distance, angles of arrival, etc).

In April and May 1962 and March 1963, scatter soundings of the ionosphere on shortwave were made at Murmansk with the object of defining the possibilities and methods of obtaining an SS echo, of plotting distance-frequency characteristics (DFC), and of comparing them with the data of the VS stations at points

* Numbers in the margin indicate pagination in the original foreign text.

of the Murmansk - Rugozero - Leningrad radio lines.

The transmitter used had a rated power of 20 kw, controlled by square /55 pulses of 2800 μsec width, at a pulse repetition rate of 50 cps, synchronized with the frequency of the power line. Reception was on a communications receiver with a bandwidth of 1 - 3 kc. Rhombic antennas directed to the south were used for reception and transmission. The signals received were fed from the output of the receiver (second intermediate frequency) to the input of an oscillograph with sweep synchronized with the line frequency. The scope of the oscillograph was photographed at exposures of 1/50, 1/25, and 1/10 sec. The sounding was conducted at 0900 - 1000 h Moscow time on fixed frequencies.

The back-scattered signals were observed on the days of quiescent or weakly disturbed ionosphere, in the absence of strong noise. We have the results of observations for 28 separate days of 1962 and 8 separate days of 1963. The SS oscillograms are shown for 21 April, 0925 h; f = 9.8 mc, in Fig.1a, b; for 21 March, 0930 h, f = 10.3 mc, in Figs.1c, d. Visually, and from the successive photographs, it is clear that the echo signals are formed on the time axis of the group, whose form fluctuates rapidly. Even at intervals of 1/50 sec, the oscillograms taken sometimes differ in detail. However, the leading edges of the group and a few extremums, on the average, occupy a more or less definite position on the time-lag axis. From simple geometric considerations it seems natural to consider (Bibl.1) that the leading edge of the echo group corresponds to the beginning of the illuminated zone, i.e., to the skip distance. As shown by Peterson (Bibl.7) for the parabolic layer, the skip distance does not correspond to the minimum time lag of the echo but to the time lag of the maximum of energy of the group of echo signals, with the difference between them going as high as one millisecond.

In general, in interpreting the SS echo pattern, one must bear in mind that the time-lag distribution of the received energy of the echo signals is affected by the form of the signal emitted, by the radiation pattern of the antenna, by the presence of refraction and losses in the lower layers, and by the scattering properties of the earth (Bibl.2). This makes it difficult to determine the skip distance and to assign an echo group to some definite layer or form of propagation, especially where several layers and several forms of propagation are involved.

Since the observations were conducted in the spring period, when E, E_s, F1- and F2-layers existed, and the exact radiation pattern of the antenna in the vertical plane and the angles of arrival of the echo were still unknown, it is difficult to give with any degree of confidence an interpretation of all the SS oscillograms, even if VS data are available at several points of the line. There still remains the possibility, by comparing the SS echo pattern with the VS data, of estimating the reliability of the interpretation and the effect /56 of these factors on the SS echo pattern and the skip distance.

From a total of 2 - 5 oscillograms, taken successively at intervals of 5 - 30 sec on one sounding frequency f, we determined the mean time lag T corresponding to the leading edges (or minima) and peaks. The variability in the echo pattern, the overlapping of the groups, the noise, and the faintness of the echo lead to great errors, $|\Delta T|$ = 0.3 - 1 msec, or even make it impossible to

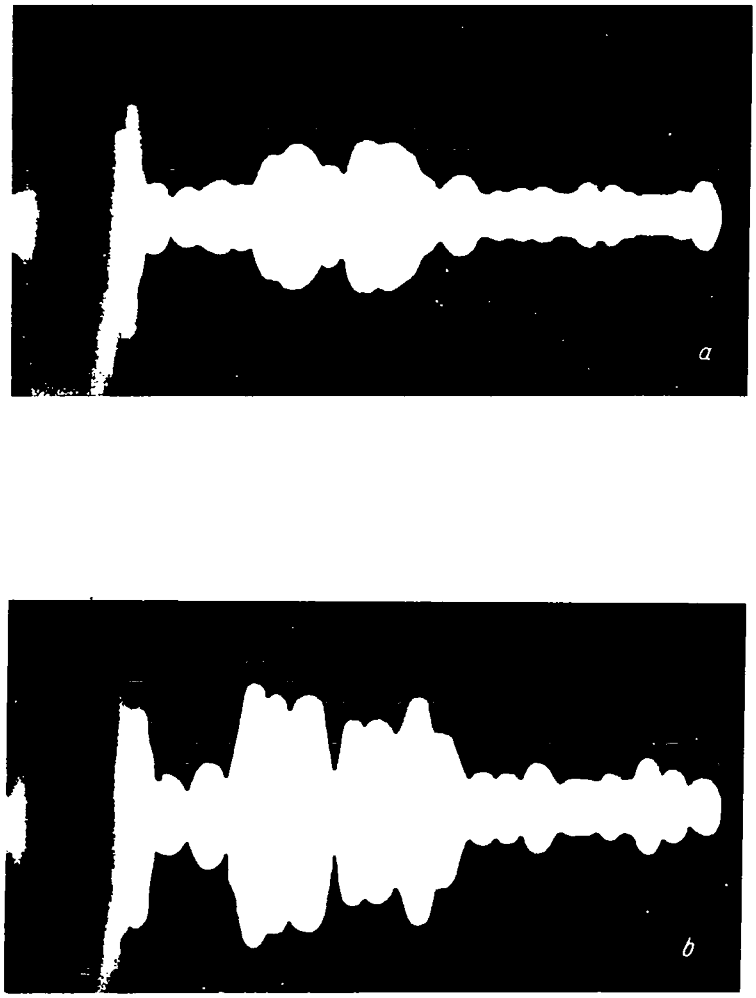

Fig.1

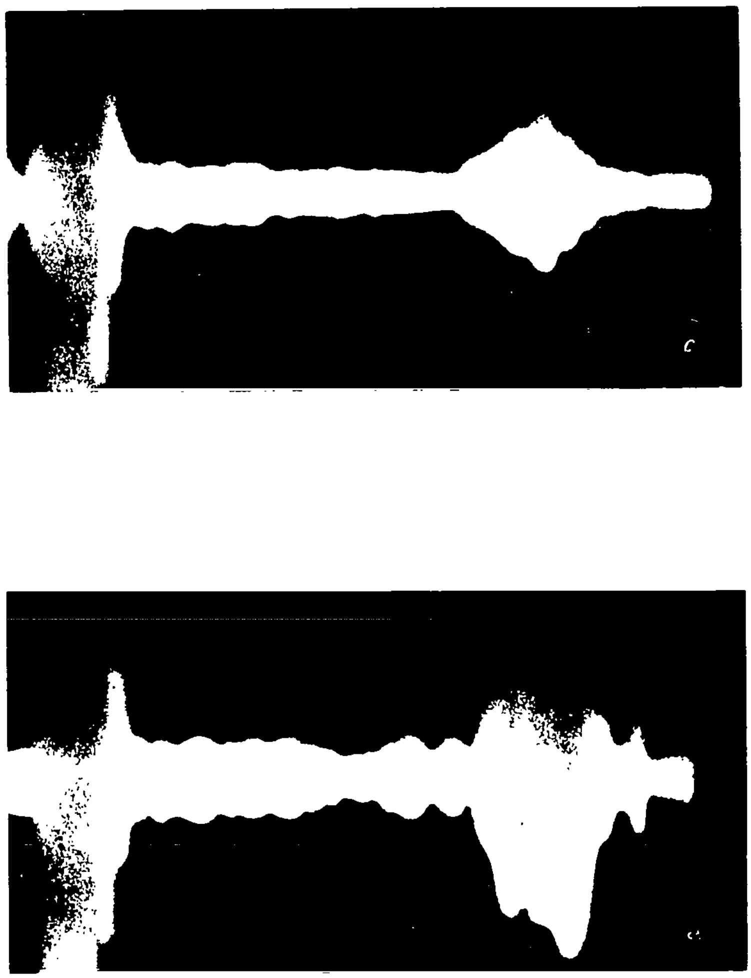

Fig.1 (continuation)

locate the group, its boundary, or its peak. From the result of the measurements for each day, diagrams like those given in Fig.2 were constructed in the form of the echo-time lag in T and f coordinates, for the distance-frequency characteristics of the SS of April 21, 1962 and of March 15, 1963; the position of the points of the leading edges of the echo groups is marked by circles and that of the peaks by short lines. The intervals of strong echoes are indicated by a heavy straight line, the weak echoes by a fine line, and the very faint and unstable echoes by a broken line, 1 - DFC'; 2 - DFC"; 3 - DFC according to VS.

For comparison with the VS data at Murmansk, Rugozero, and Leningrad, we used these data in calculating the MUF for the distances for which the data of the point are averaged; the Murmansk point of course corresponds to the critical frequency for VS. In calculating the MUF E and MUF E_s, we used the 25-min values of f_0E and f_0E_s, closest to the time of sounding, or the arithmetic mean of the most recent hourly VS data. The calculation was performed graphically according to the alignment chart given in the monthly forecasts of IZMIRAN (Institute of Terrestrial Magnetism and Radio Wave Propagation, USSR Academy of Sciences) for conversion of the E-MUF2000 into MUF for other distances. In calculating the MUFF1, we used the most recent 25-min values of f_0F1 or the arithmetic mean of the most recent hourly values, and also of h_pF1, taking the same h_pF1 of Rugozero as the h_pF1 of Leningrad. From this h_pF1, we determined the F1MUF3000 from the Table (Bibl.9) used at the PGI (Polar Geophysical Institute) or, in the case of a definite F1MUF obtained by the NBS method, we used the latter. The conversion to 1000 and 2000 km was performed on the basis of the nomogram for converting the F1MUF3000 into the MUF for other distances.

The calculation of the F2MUF was similar, but in this case more use was made of the Leningrad values of h_pF2. Thus, the MUF obtained for 0, 1000, 2000 km were plotted in T, f coordinates, for which purpose the ground distance D was converted into distance over the equivalent arc corresponding to the time lag T, according to graphs (Bibl.1, 5) based on the geometry of propagation. We constructed the scale of D on the T axis for certain reflection heights: hE = = 100 km, hF1 = 200 km, hF2 = 300 km. These scales, beginning at the point T = = 2h, are close together at first, but from about 800 km are linearly shifted to h = 100 km. We consider that, for the given accuracy of measurement, the accuracy of this operation is sufficient. Thus, the resultant points were connected by a broken line, which represents the DFC according to the VS data (Fig.2).

Depending on the presence of an echo at various frequencies, and on the possibility of interpretation for the 28 days, we succeeded in 21 cases in constructing the DFCI from two points of the leading edges of the nearest group (DFCI') or, adjacent to the boundaries of the groups, of the peaks of their leading edge (DFCI"), in 16 cases from three points, and in seven cases from four points. On 14 days, the DFCI' and DFCI" approximated the DFCE. In these cases, the DFCII was closer to the DFCF1 than to the DFCF2. In nine cases, there are near echoes, giving a DFCI considerably to the left of the DFCE, when the DFCII corresponds to the DFCE while the DFCIII is closer to the DFCF1. It may be assumed that those echoes correspond to the E_s and F2-layers with elevated MUF, or to this echo from a distance greater than 3000 km (along the arc). However, the latter should be faint, which was not always the case. Based on /57 the use of rhombic antennas (Bibl.8) giving maximum radiation at small angles to the horizon, it may be postulated that at low frequencies and small distances the F2-layer will be strongly shielded by the E- and F1-layers. Moreover, the MUFF2 are less stable from day to day. We therefore consider that the E- and F1-layers give stronger echo groups and stable DFC. Comparison of these /58

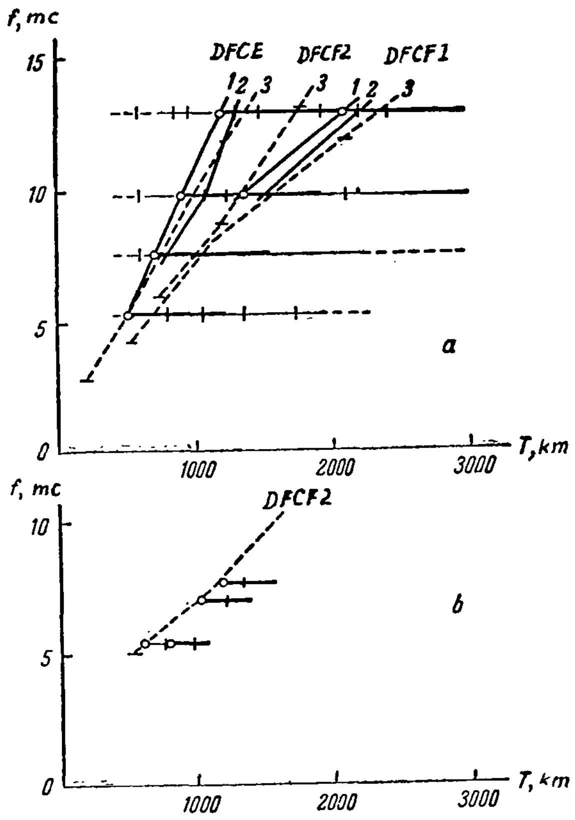

Fig.2

DFC with the VS DFC shows that the role of the layers in the formation of strong echo groups and their DFC is in most cases correctly determined. It is difficult, however, to determine the two-skip distance. The near echoes, which were found on 14 days, in nine cases give DFCI for two points and in seven cases for three points, so that the DFCI lies substantially to the left of the DFCE. On seven such days there are DFCF2 of VS according to f_0F2, which are likewise to the left of the DFCE, and in four cases DFC of the near echo approaches the DFC of E_s, when the latter could be plotted from the data $f_0E_s > f_0E$ at Murmansk and Rugozero; but almost always, for the near echoes at Leningrad there was $f_0E_s > f_0E$, while the MUFF2 are also substantially less than the MUFE. Consequently, there are more grounds for assuming that sporadic formations in the E region, which perhaps themselves are back-scattered, are responsible for the near echoes.

A determination of the skip distance involves the interpretation of the

TABLE 1

Layer	E				F1				F2			Es		
Frequency, mc	5.3	7.6	9.8	12.9	5.3	7.6	9.8	12.9	7.6	9.8	12.9	7.6	9.8	12.9
Median Δb, km	—	—20	—20	—100	—60	0	0	—100	—	100	0	0	—100	100
Median Δn, »	40	80	100	80	20	60	100	40	90	130	130	<100	20	20
$\overline{\Delta b}$, km	—	—36	—28	— 70	—60	—20	—10	— 60	—	100	—16	0	—160	—92
$\overline{\Delta n}$, »	48	80	80	40	30	92	80	60	60	130	80	<100	— 20	0
σb, »	—	52	60	100	32	85	96	84	—	72	136	—	—	140
σn, »	70	74	82	70	90	90	90	104	100	90	96	—	—	110

TABLE 2

Layer	E				F1				F2			Es		
Frequency, mc	5.3	7.6	9.8	12.9	5.3	7.6	9.8	12.9	7.6	9.8	12.9	7.6	9.8	12.9
$\|\Delta b\| < \|\Delta n\|$, km	—	9	8	4	0	6	6	7	—	3	6	2	0	2
$\|\Delta b\| > \|\Delta n\|$, »	—	4	4	7	7	5	7	8	—	2	3	1	6	5

details of the individual group, the leading edge, and the peak of the front. The difference between DFC' and DFC" in a number of cases reaches a distance of about 250 km or, in frequency, of about 2 mc.

To estimate the degree of agreement between the SS and VS data, we made the following examination of the deviations of the DFC' and DFC" from the DFC VS. First, we determined the mean deviation of the time lag (in km) of the leading edges and peaks of the forward front of the echo groups on the sounding frequencies, and also the mean and the mean-square deviation (Table 1). Secondly, we determined the number of cases in which the deviation of the leading edge $|\Delta b|$ was more or less than the deviation of the corresponding peak $|\Delta n|$, for the cases $|\Delta b(n)| \lesssim 10\%$ (Table 2).

It will be seen from Tables 1 and 2 that, on 5.3 mc, the peak of the leading edge of the echo group of the E layer deviates on the average by +50 km (the leading edge of the group is overlapped by the radiated pulse itself). On 7.6 and 9.8 mc, the mean deviation of the leading edge is less than, or approximately equal to, -40 km, while the mean deviation of the peaks is +80 km. On 12.9 mc, the overwhelming majority of the leading edges are closer; on the average, -70 km. It may be noted that the interval between the leading edge and the peak tends to increase with the frequency, which points to an effect different from focusing by the parabolic layer.

For the F1-layer on 5.3 mc, the mean deviation of the peaks is only +30 km, and the leading edges usually overlap with the E group. Several distinct cases indicate that the interval between this peak and the leading edge may be approximately 150 km. On 7.6 and 9.8 mc, the mean deviation of the leading edge /60
approaches zero. The mean interval between the edge and peak on 7.6 mc is less than on 5.3 mc, but it does not decrease on the following frequencies, which likewise indicates the indeterminacy of the focusing. On 12.9 mc, the mean deviation of the edges is 60 km, and that of the peaks is ±60 km. It may be noted that, in 33% of the cases, the leading edge coincides with the DFC VS. For the F2-layer the results are insufficient, since its group, even if it does exceed the noise level, is masked by E- and F1-groups or by the E_s group. The infrequent SS data that are comparable with the DFCE_s show a greater variance, sometimes exceeding 200 km.

It will be clear from Table 2 that for most E layer cases, taken separately, except for the case of frequency 12.9 mc, the deviation of the leading edge is less than that of the peaks. For the F1-layer at low frequency, at which the skip distance is short and the angle of downcoming is less than on higher frequencies and for greater skip distances, the deviation of the peaks, corresponding to the focus, is less than at higher frequencies, where, apparently, the effect of the other factors is stronger. It would, however, be too optimistic to consider that the DFCF1 VS exactly determine the actual skip distance from the F1-layer, ignoring such factors as the refraction in the E or E_s layer, the influence of the geomagnetic field, and the horizontal gradient of ionization of the F1-layer.

In March 1963, scatter soundings were made at a pulse width of 1000 μsec. At that time, the lower E- and F1-layers were still weak, and the sporadic E(E_s)

appeared rarely in the morning hours. For this reason, we obtained simpler /61
SS oscillograms containing a single group of back-scattered echoes (Fig.1c, d).
A comparison with the VS data confirms the fact that these echoes are due to back-scattering from the earth and reflection from the F2-layer. Here the leading edge of the echo group agrees with the skip distance of the extraordinary

TABLE 3

March	Frequency, mc			
	5.3	6.9	7.6	10.3
14	—	120	60	0
15	0	— 20	0	—
16	—	100	0	140
18	100	—100	—20	20
20	0	0	80	—70
21	—	100	20	—70
22	0	0	—30	—
23	—	—	140	100
Range of skip distance, km	0—700	600—1000	800—1300	1200—1600

ray according to the VS data (Fig.2b). The level of the echo signals of the extraordinary ray near the leading edge is considerably lower than the peak of the entire echo group. The deviations (in km) of the leading edge of the echo groups from the skip distance are given in Table 3.

CONCLUSIONS

1. The transmitter power used, the antenna, and the receiving and recording equipment permit observation of the back-scattered echoes from ground distances of the order of 400 - 6000 km, even at small disturbances of the ionosphere, for example, in the absence of VS reflections at Murmansk.

2. The use of the VS data at control points of the route, or even at its initial point, may considerably facilitate the interpretation of the echo field pattern if there are several reflecting layers.

3. If we start out from the fact that the existing simple methods of calculating the MUF from the VS data at the midpoint of the route are satisfactory and that, at distances of about 400 - 2000 km, the VS DFC can be represented with sufficient accuracy (for practical purposes) in the form of a broken line through 2 or 3 points, then the following conclusions can be drawn: a) the skip distance from the E-layer at distances of about 400 - 2000 km are satisfactorily (±10%) determined by the leading edge of the echo groups in the E-layer; b) at distances up to 800 km, the skip distance from the F1-layer is determined on the

average by the peak of the leading edge F1 of the echo group, which means that there is a marked focusing effect; at distances over 800 km, the skip distance is on the average determined (±10%) by the leading edge of the echo group of the F1-layer; c) secondary factors, especially the radiation pattern of the antenna, did not lead to more than 10% deviations in the determination of the skip distance from the E- and F1-layers; d) in the morning hours (0900 - 1000 h) of April and May, at these directions and distances, E and F1 are the principal layers in shortwave propagation at frequencies of 4 - 13 mc.

4. Under winter conditions of the ionosphere, good agreement of the SS and VS data is noted for the F2-layer. Under summer conditions of the ionosphere, a study of the role of the F2 and E, layers on this route, lying in the polar and subpolar latitudes, demands more exact systematic observations, measurements of the angles of arrival, and of the intensity of the echo field. Comparison /62 with the VS demands exact coincidence of the times of sounding and the method of calculating the MUFF2, taking account of the influence of the lower layers and of the horizontal gradient of ionization.

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MUTUAL POSITION OF THE CURRENT S_D-VORTICES AND THE MAIN ZONE OF POLAR AURORAE */63

N. S. Smirnov

The current system responsible for the mean S_D-variation over the earth's surface was constructed on the basis of magnetic data from 16 Observatories located in the auroral zone and on the polar cap. The position of the central electrojet of the system is compared with the position of the main auroral zone. The corpuscular target zone, corresponding to the position of the electrojet of the S_D-vortex, exists statistically as an integral whole and is closely linked with the earth's surface. No closed current ring, corresponding to the closed auroral ring, was detected.

The idealized system of S_D-currents responsible for the S_D-variation of the magnetic elements was first constructed by S.Chapman (Bibl.1) from a very small amount of material of magnetic observations. The pattern he obtained was symmetric relative to the line Earth - Sun, and both vortices were of the same intensity.

Subsequently, H.Silsbee and I.Vestine (Bibl.2), on the basis of the same material, constructed a current system closer to the actual distribution of the S_D-variations on the earth's surface, in which the center of symmetry was shifted westward by about $40°$, and the day vortex was of lower intensity.

Still later investigators [Ben'kova (Bibl.3), Fukushima and Oguti (Bibl.4)] refined the system of S_D-currents and its position, although none of them doubted the actual existence of regular S_D-variations in the high latitudes.

Moreover, some authors (Bibl.4) pointed out that the day vortex was substantially weaker than the night vortex and that the S_D-current system was merely an averaged pattern, while in individual specific disturbances the positive day vortex might be absent altogether. Disturbances with a positive phase (positive bays), but no negative phase (negative bays) have also been observed in the polar latitudes, though very seldom.

It was also established that the zone of maximum density of the current vortex (the auroral zone) is shifted relative to its mean position, depending on the degree of geomagnetic disturbance (Bibl.5, 6).

O.A.Burdo (Bibl.7) later doubted the existence of any regular S_D-variations

* Numbers in the margin indicate pagination in the original foreign text.

in the high latitudes, as an independent geophysical phenomenon unrelated to the D_i-disturbances.

A characteristic feature of the S_D-current system is the marked clustering of the current lines near the auroral zone. There is no doubt whatever that /64 this indicates the corpuscular nature of the S_D-variation and permits us to postulate that in space the S_D-currents or, more accurately, the central electrojet of the S_D-vortex, coincide with the region of arrival of the corpuscular flux in the upper atmosphere. This hypothesis is confirmed by the coincidence of electric currents in the ionosphere with the auroral displays (Bibl.6). Thus, the position of the central electrojet of the S_D-vortex evidently permits us to judge the position of the target zone of the corpuscular flux.

O.V.Khorosheva (Bibl.8) constructed a closed ring (oval) of the aurora, likewise identifiable with the target zone. This ring differs considerably in shape from the mean auroral zone for all hours and for maximum magnetic activity, and coincides with it only in the night hours, while it shifts far to the north in daytime.

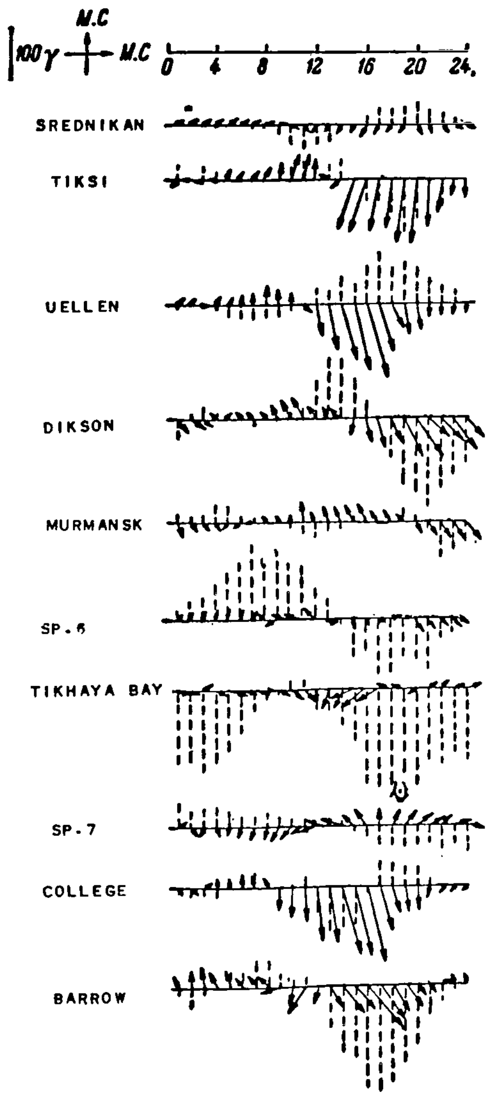
Starting from the above, it was of interest to construct the current system responsible for the mean S_D-variation observable for an individual specific period, and to compare the position of the central electrojet of that system with the position of the auroral zone obtained from the auroral observations during the same period.

Available to us were the materials of magnetic observations for December 1957 from 16 magnetic observatories located in the main auroral zone, in the subzone, and in the polar cap [the closed auroral ring and, as a result of its diurnal drift, the auroral zone were constructed by O.V.Khorosheva (Bibl.8) in the winter of 1957 - 1958].

Of all the days of December 1957, from the magnetograms of the Minuk Observatory, we selected 18 days of various degrees of disturbance, but not less than a certain minimum, defined by the existence of deviations lasting 6 hrs and perceptible on visual examination of the magnetograms, from the quiet march of the magnetic elements. Then, for all available observatories, we calculated the S_D-variation, as the difference between the mean diurnal marches for the 18 selected disturbed days and five international quiet days. The materials of some observatories (Thule, Resolute Bay, Baker Lake, Yellowknife, Churchill, Minuk) did not contain tables of the mean hourly values of the magnetic elements, and were worked up by taking, from a template superposed on the magnetogram, hourly indexes characterizing the value of the deviation from the quiet march, which considerably accelerated the work-up.

The error of such a determination of the S_D-variation is of the order of 10%.

For the drifting stations SP-6 and SP-7, we had to select the following technique: The mean diurnal value was calculated from each mean hourly value; the resultant relative mean diurnal values of the variation were averaged for the 18 days selected; the quiet march obtained in the same way for the five /66 international quiet days was subtracted from these. The external part of the


100γ
M.C
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4
8
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20
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SREDNIKAN
TIKSI
UELLEN
DIKSON
MURMANSK
SP-6
TIKHAYA BAY
SP-7
COLLEGE
BARROW

Fig.1

S_D-currents was separated by multiplying the horizontal components of the geomagnetic field by 2/3, and Z by 3/2.

All the material obtained is shown in Figs.1 - 2 in the form of vector diagrams of ΔT_{hor} (arrows) and ΔZ (broken lines). Figure 1 shows the vector diagrams of observatories obtained from mean-hour tables of values for the magnetic elements and oriented relative to the magnetic meridian, while Fig.2 contains vector diagrams oriented relative to the geographic meridian. Having the vector diagrams of 16 magnetic observatories, it was possible to construct the S_D-vortex for each hour of the day and to follow up its deformation; however,

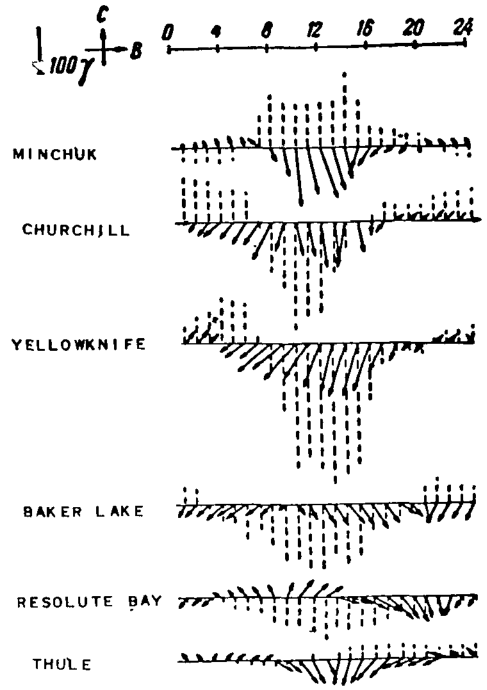

Fig.2

guided by the data of the available stations, we constructed the vortices only for three times: a) for 1000 h GMT, which approximately corresponds to the time of the maximum positive disturbances in the Soviet sector of the Arctic and of the negative disturbances at the observatories on the American Continent (Fig.3); b) for 1600 h GMT, when the night maximum of disturbance is observed at the center of the available series of stations (Fig.4); c) for 2200 h GMT, at a time close to the local geomagnetic midnight for the western sector of the Soviet Arctic (Fig.5).

The vortices were constructed as follows: On the map, we plotted the position of the observatory (the positions of SP-6 and SP-7 were taken as the mean of the six positions given respectively for December 5, 10, 15, 20, 25, 30, 1957) and the vector of disturbance ΔT_{hor}, together with the position and direction of the current for the corresponding hour. The position of the current was determined by the formula:

$$d = h \cot \alpha = 110 \frac{Z}{H}. \tag{1}$$

In general, this formula is true only for linear currents, but it can also be applied to the zone where there is a current of 200 - 500 km width extending along the zone up to 2000 km (Bibl.9). In the polar cap, of course, only the direction of the current perpendicular to the vector of disturbance can be determined. /67

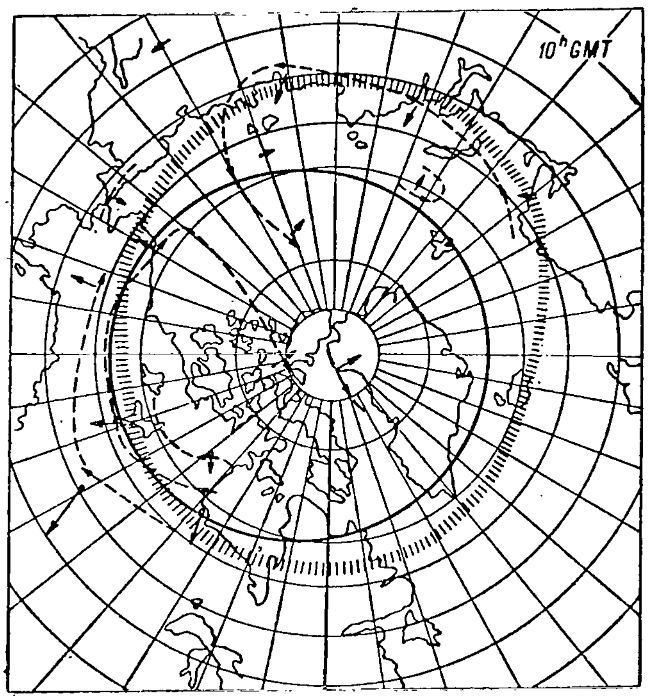

Fig.3

On the map (see Figs.3 - 5), we also plotted the position of the auroral ring at the given time, and the position of its envelope which, according to Khorosheva (Bibl.8), is formed by the diurnal drift of the ring.

It will be clear, from a consideration of their mutual positions at the same periods of time, that the day and night S_D-vortices generally, at least statistically speaking, exist simultaneously for the period considered and are of comparable intensity, while the central electrojets of the S_D-vortex are disposed along the envelope of the ring, which coincides with the auroral zone, or the target zone of corpuscular streams.

Moreover, as distinctly shown by Figs.3 - 5, the central electrojet of the day S_D-vortex has no connection with the auroral ring identified by O.V.Khoro-

sheva (Bibl.8) or with the target zone of the corpuscular streams, and the /68
night current S_D-vortex whose central electrojet coincides with the night side of the auroral ring, is closed across the polar cap and does not osculate the ring.

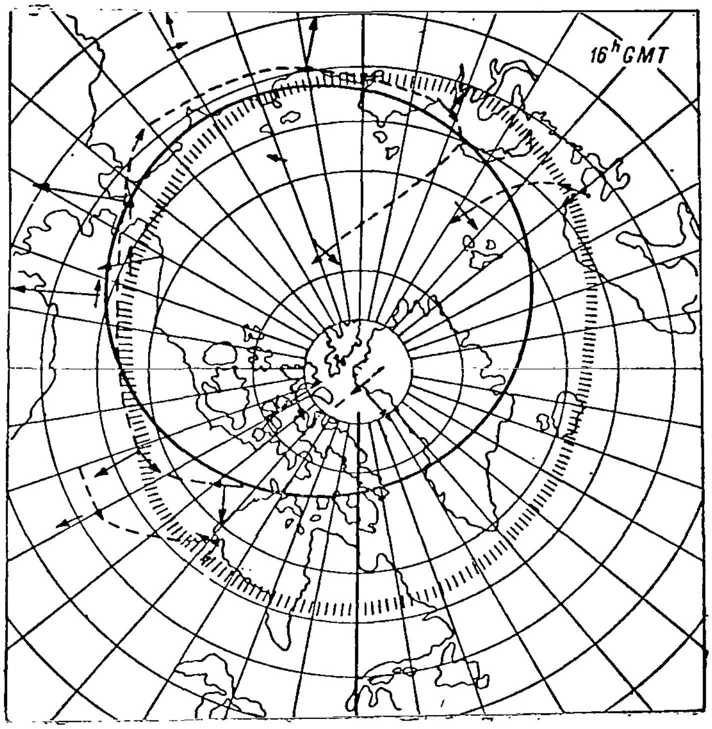

Fig.4

Very similar to the closed auroral ring were the night and morning spirals of O.A.Burdo (Bibl.7), forming an oval, but even these are not current lines, or electrojets, as E.Hope called them (Bibl.10). O.A.Burdo already noted that his spirals resembled the lines of maximum density of the currents obtained, under certain reasonable assumptions, on the basis of the dynamo theory of geomagnetic disturbances, although he did not specifically designate them as current lines. The spiral dependence of the time of occurrence of the disturbance maxima on the geomagnetic longitude is determined only by the position of the observation points on the earth's surface, on which also depends the instant of time at which this point, in its diurnal motion, encounters the part of the S_D-vortex of elevated current density, and how often such an encounter occurs. In turn, the density of the current is determined not only by the intensity of the corpus- /69
cular flux but also by the diurnal march of the emf.

A comparison of Figs.3 - 5 shows that, at a given time, no matter where the central electrojet of the day S_D-vortex may happen to be relative to any point of the earth's surface, this is where also the central electrojet of the night S_D-vortex will be after a time interval of about half an hour.

It follows from the above that there exists statistically a target zone which coincides with the envelope of the closed auroral rings and is closely connected with the earth's surface of the target zone, where the various portions of this zone are distinguished only by the probability and intensity of the corpuscular invasions. The orientation of the auroral forms may serve as a confirmation of this postulation.

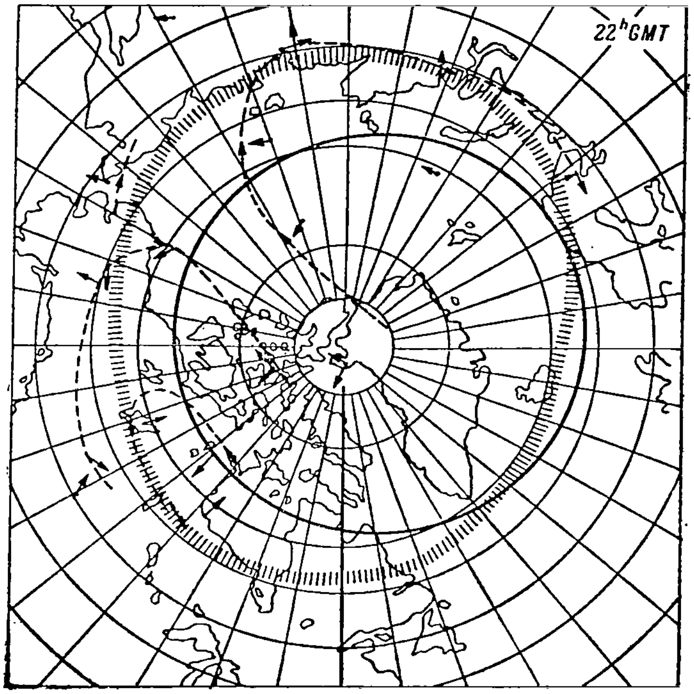

Fig.5

In fact, the orientation of the stable forms of the aurora and their position, coinciding with the position and direction of the central electrojets /70 of the S_D-vortex, persist even at the instant of their alteration, which points only to a change in the direction of the emf at the given instant of time, causing a rotation (bending) of the current lines [see also (Bibl.6) and the papers by V.K.Roldugin and G.V.Starkov in the present symposium].

K.Cole, considering the system of S_D-currents constructed by N.Fukushima and T.Oguti (Bibl.4) to be close to reality, asserts that the current lines and auroral forms coincide in direction even at the times of change of the vortices, but this assertion is based (Bibl.12) on scanty experimental data.

CONCLUSIONS

1. The corpuscular target zone, corresponding to the position of the electrojets of the S_D-vortex, exists statistically as an integral whole and is

closely connected with the earth's surface.

2. No closed current ring corresponding to the closed auroral ring has been detected from the geomagnetic data.

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RESULTS OBTAINED FROM INVESTIGATIONS OF THE S_D-VARIATIONS IN HIGH LATITUDES */71

G.A.Loginov

Previous investigations of the S_D-variations in high latitudes are extended to include studies of the rotation of the horizontal vector of disturbance on northward shift of the auroral zone at decreasing solar activity. Plottings of the diurnal march of the disturbance vector, in both the horizontal and vertical plane, show that the horizontal vector remains approximately parallel to itself, along the geographic meridian. Reversal of the direction takes place counterclockwise over Murmansk and clockwise over Uellen. The general direction is determined by the direct dynamo action of the ionospheric wind and by the electrostatic field at the junction of eastern and western "electrojets". Differences in degree of rotation in 1958 and 1961 indicate that the auroral zone shifts northward with decreasing solar activity.

We have shown elsewhere (Bibl.1) that the diurnal march of δH, calculated for certain specific days of moderate disturbance, can be explained from the viewpoint of the dynamo theory. By multiplying the intensity of the aurora δI by the value of the meridional component of the ionospheric wind $V_\perp$, we obtained a variation of δH analogous to the march of δH observed on the same days. At the same time, we advanced the hypothesis that, since the observed march of δH differs from the S_D-variation H only in amplitude, the S_D-variation can also be explained by the diurnal march of the ionospheric wind. However, the horizontal vector obtained on multiplying δI by $V_\perp$ should, throughout the disturbance, be perpendicular to the target zone, and the times at which $\delta H = 0$ should coincide with the times at which $V_\perp = 0$.

Actually, as has been repeatedly pointed out, the horizontal vector at some stations rotates during the course of the day.

The purpose of the present work was further to investigate the S_D-variation at certain stations located in high latitudes, and to explain the observed behavior of the horizontal vector of disturbance.

The starting material consisted of the mean hourly values of three elements of the geomagnetic field (H, D, Z) observed at Murmansk during the period from July 1958 to December 1961, at Dikson and Tikhaya Bay (Hayes Island) during the period from January 1957 to December 1959 and at Uellen Station in December 1957.

* Numbers in the margin indicate pagination in the original foreign text.

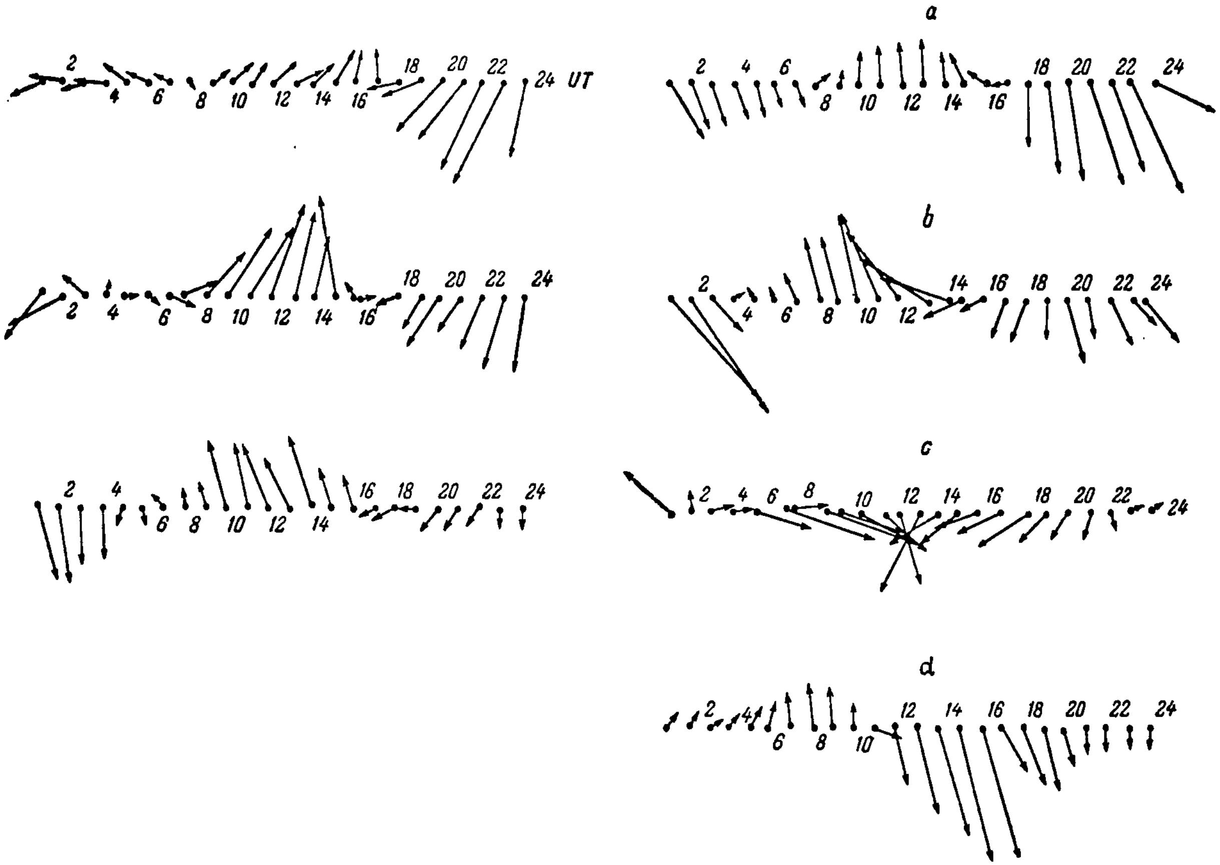

Fig.1

The mean monthly S_D-variation of each element was determined as the difference between the mean values of the element for five disturbed and five quiescent days of a given month. To ensure uniformity of the data, the international quiet and disturbed days were used in the work-up. So as to determine the position of the current in the ionosphere, we separated the external part /73 of the disturbed magnetic field, which was taken as equal to 2/3 of the observed horizontal components and 3/2 of the vertical component.

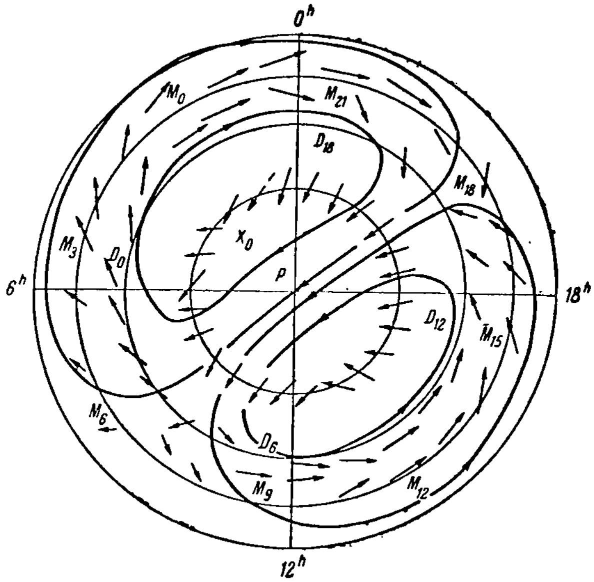

Fig.2

From the obtained data we plotted the diurnal march of the vector of disturbance in the horizontal and vertical planes, permitting us to judge the direction and position of the currents. Figure 1 is an example of these graphs. On the left we show the diurnal march of the vertical vector, and on the right that of the horizontal vector, for Murmansk (a), Dikson (b), Tikhaya Bay (c) and Uellen (d).

In studying these graphs it must be borne in mind that the direction of the horizontal vector is given here relative to the magnetic meridian of the station.

The diagrams also show that at Murmansk, during almost the entire day and night disturbances, the horizontal vector remains approximately parallel to itself and is directed along the geographic meridian. It will be seen that the reversal of direction of the vector occurs counterclockwise. At Dikson, the counterclockwise rotation of the vector is more apparent and is observed for a longer time; the horizontal vectors maintain a mutually parallel position only for a few hours near the maxima. The diurnal march of the horizontal vector /74 for December 1957 at Uellen station, is generally similar to the diurnal marches at Murmansk and Dikson but differs from them in that, at the moments of change of direction of the vector, its rotation is clockwise. This behavior of the horizontal vector of disturbance may be explained by the general character of the currents of the S_D-variation system, provided that one can demonstrate that the variation in the magnetic field observed at the above stations is determined by this current system. With this object, we plotted in Fig.2 the positions of

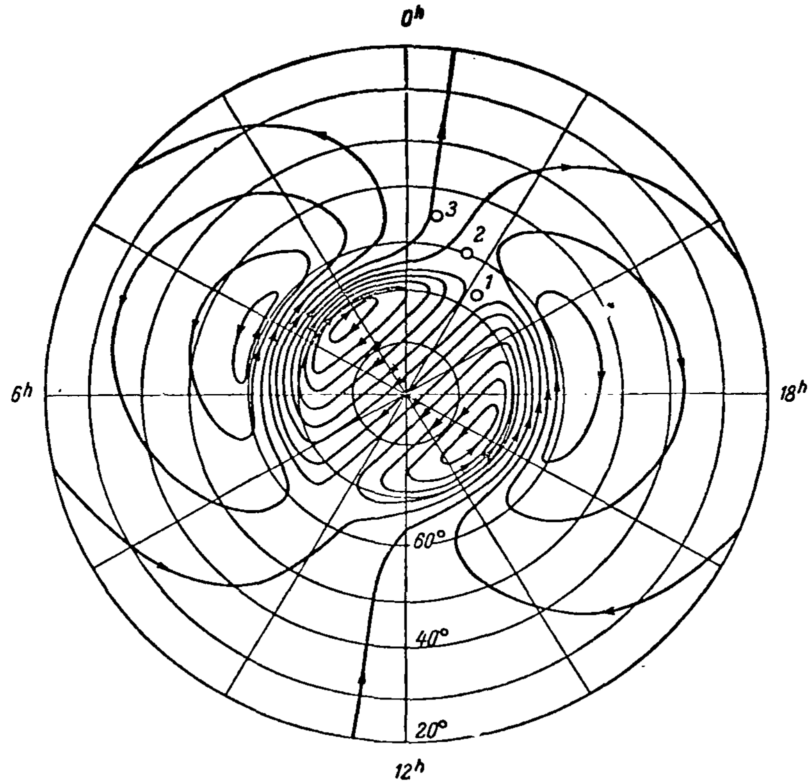

Fig.3

the currents observed at the stations of Murmansk (M), Dikson (D), and Hayes (H) for each hour of local time. The subscripts to the station name indicate the corresponding Universal Time. The resultant current pattern is in good agreement with the shape of the current system of the S_D-variation, shown for comparison in Fig.3 and borrowed from Fukushima's data (Bibl.2). It can be concluded from the configuration of this system that, near the time of change in direction of the current, a spreading of the current is observed. Some of it proceeds North in the evening, closing the eastern and western vortices across the polar cap, and some of it runs South and closes the same vortices in the middle and low latitudes. Consequently, at this time, at the stations located South of the zone, a southern current should be observed, with the vector rotating clockwise. At the stations located North of the zone, a northern current should be observed, with the vector rotating counterclockwise. If a station is located close to the center of the current belt, a sharp transition from the positive horizontal vector (eastern current) to the negative (western current) is inevitable. With increasing northward distance of the station, the transi- /75 tion takes longer and the horizontal vector changes its direction gradually, rotating counterclockwise.

YEAR	DAY	NIGHT
1958	—	—177
1959	—78	—135
1960	—39	— 93
1961	— 3	— 19

Hence it likewise follows that the character of the behavior of the horizontal vector can be used for defining the position of the station relative to the auroral zone (here and below, the position of the auroral zone is identified with the position of the central jet of the current vortex). Thus, in particular, it may be asserted that Dikson Island in the year under consideration was located further North of the zone than Murmansk. From the data of Murmansk, the shifting of the zone with varying solar activity can also be traced. Figure 4 shows graphs of the horizontal vector for September 1958 (a) and November 1961 (b), from which it is clear that the rotation of the vector in 1958 was more marked than in 1961. This means that with decreasing solar activity the zone shifts northward.

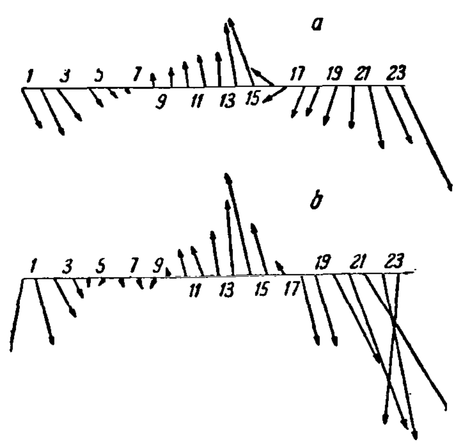

Fig. 4

Our hypothesis that Murmansk, in the years under consideration, was located North of the zone and that the zone shifts northward on a decrease in solar activity is confirmed by a direct calculation of the distance from the station to the projection of the current onto the earth's surface at the times of the /76
day and night maxima. To simplify the calculation, we assumed that the current flowing at a height of 100 km is linear. The minus sign means that the current is located to the south.

Thus, the hypothesis that the S_D-variation of the H-component obeys the formula $\delta H = V_{\perp} \delta I$ may be considered valid only for stations located directly in the auroral zone or 1 - 2° distant from it. With a greater distance from the zone, the direction of the horizontal vector is determined not only by the direct dynamo action of the ionospheric wind but also by the electrostatic fields that arrive in the regions of "junctions" of the eastern and western electrojets, and by the current divergence caused by these.

YEAR	MONTH											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1958	—	—	—	—	—	—	17	18	16	16	19	14
1959	17	17	16	18	18	18	17	15	16.5	17	16	15
1960	17.5	18	17	17	18	18.5	17	17	17	15.5	18	15
1961	18	18	17	17	18	18	16	18	18	15	17	16

A study of the graphs made it possible to establish the time of change in sign of δH at Murmansk; on the average, for the 3.5 years of observation, these changes occurred at 0700 - 0800 and 1700 - 1800 h Universal Time, i.e., at 0900 - 1000 and 1900 - 2000 h Zone Time. At Dikson, the same phenomena, for a three-year average, occurred at 0400 and 1400 h UT or at 0900 and 1900 ZT. However, these times are not constant and shift during the year and during the cycle of solar activity. The accompanying Table illustrates the seasonal variation in the time of change in sign of δH at Murmansk. There is a marked shift to earlier times in the equinoctial months, which was noted by Bryunelli (Bibl.3), with reference to Robertson (Bibl.4). The vagueness of this shift is explained by the low accuracy of the method used in distinguishing this time, which consisted in using the International Quiet Days, when the field at a given station might actually not have been entirely quiescent. This error is increased by the fact that, at the time of transition, the vector of disturbance is small. The fact that, on days with different degrees of disturbance, the change in sign of δH takes place at different times also has its effect on the accuracy of determination of the time of this phenomenon over the mean monthly march.

Figure 5 illustrates the shift in time of occurrence of the zero value of δH during the cycle of solar activity for Dikson (curve D) and Murmansk /77
(curve M), together with the curve of the activity itself (curve K).

Figure 6 shows the time of $\delta H = 0$, plotted against the angle of inclination of the horizontal vector relative to the geographic meridian φ; the dots correspond to days of moderate disturbance, and the circles to days of elevated disturbance. It will be seen that the times of occurrence of $\delta H = 0$ on days of moderate disturbance fit rather well on a straight line, with the exception of Uellen.

For days of elevated disturbance, data were obtained only for Murmansk and College. Even they, however, are sufficient to show that, with increasing activity, the time of $\delta H = 0$ shifts to earlier hours. Obviously this displacement is related to a decrease in the angle φ, but this decrease cannot explain the entire value of ΔT (otherwise the currents corresponding to disturbed conditions would likewise have to fit on the straight line in question). Consequently, besides the rotation of the horizontal vector (decrease in φ) at the time of occurrence of δH = 0, the displacement of the current vortex along the meridian also exerts an influence.

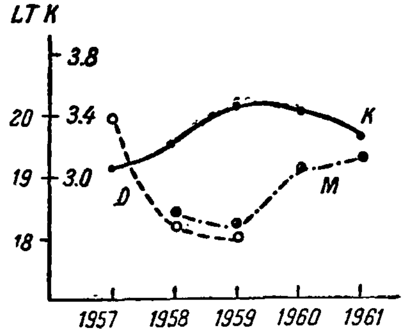

Fig.5

All above facts permit the conclusion that the shift of the zone toward the Pole causes a shift of the time of δH = 0 toward later hours, while the shift of the zone to the south causes a shift of the time of δH = 0 toward earlier hours. In other words, at stations North of the zone, δH = 0 occurs at earlier local times than at stations South of the zone (this may also explain the extensive scattering of the Uellen data in Fig.6).

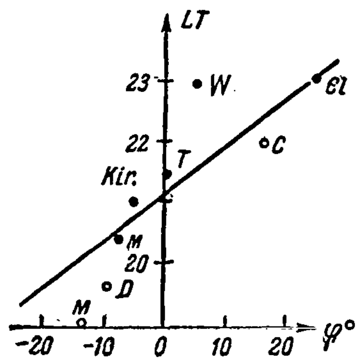

Fig.6

It is still difficult to give a complete explanation of the above fact, but it seems to be a logical result of the character of the S_D-current vortices. Actually if, in Fig.3, we locate the points where δH = 0 should take place (points 1, 2, 3), it becomes obvious that, with a shift of the stations to the south, the time of occurrence of δH = 0 increases. /78

A number of papers (Bibl.5 - 7) discuss the question of the mutual positions of the ionospheric current and the auroral arcs. One author (Bibl.5) shows that, in the auroral zone, the horizontal vector is perpendicular to the auroral arc in the night hours while another author (Bibl.6) asserts that "in first approximation the diurnal march of the azimuths of the currents resembles the march of the azimuths of the arcs". However, the approximate coincidence of the azimuths of the arcs and currents is canceled as soon as the currents change direction. Judging from the data by Poldugin (Bibl.6), the azimuth of the arcs varies only slightly before this time, during it, and after it, and never shows any surge or jump. At the same time, it is obvious from the present study that the direction of the current, around the times when the H-component changes sign, gradually varies by 180°. We have also shown elsewhere (Bibl.1) that, at the time when δH changes sign and when the latitude component of the current passes through zero, the intensity of the aurora increases continuously. Hence the conclusion can be drawn that the aurora exists independently of the existence of currents in the ionosphere, although the cause of both aurora and currents is the invasion of the earth's atmosphere by corpuscular streams. However, if the aurora is a direct result of excitation of atoms and molecules of air, it follows that some emf must be necessary for the occurrence of currents [besides the formation of the zone of elevated conductivity (elevated ionization)] formed simultaneously with the excitation. This emf, according to the dynamo theory, is produced by the ionospheric wind, but only if its component normal to the zone of invasion is nonzero. When δH changes sign, however, the velocity $V_{\perp}$ is close to zero, and, despite the existence of a zone of elevated conductivity, no current is observed along it. The current existing at this instant is directed along the meridian (or close to it), as a result of the action of the electrostatic field of the space charge which arises at the "junction" of the easterly and westerly currents.

CONCLUSIONS

1. The character of the rotation of the horizontal vector of disturbance is determined by the position of the observatory relative to the auroral zone.

2. In 1958 - 1961, the auroral zone was located to the south of Murmansk Station, and shifted to the north with decreasing solar activity. The shift of the zone causes a change in the character of rotation of the horizontal vector of disturbance.

3. The time at which $\delta H = 0$ undergoes seasonal variations, and also varies during the 11-year cycle of solar activity, is connected with the shift of the auroral zone.

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